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(54) SUBSURFACE ALIGNMENT METROLOGY SYSTEM FOR PACKAGING APPLICATIONS

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(52) **U.S. Cl.**

CPC ***H01L 21/681*** (2013.01); *H01L 24/80* (2013.01); *H01L 2224/8013* (2013.01)

(58) **Field of Classification Search**

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See application file for complete search history.

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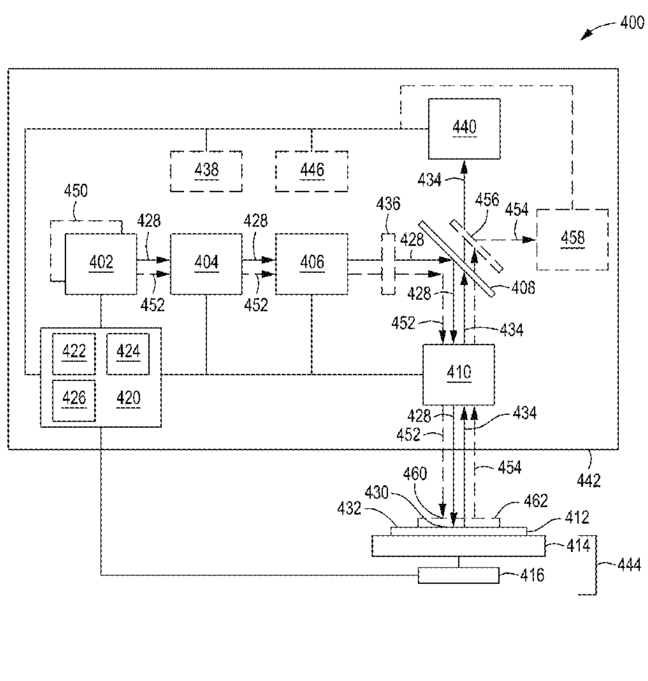
(74) *Attorney, Agent, or Firm* — Moser Taboada

(57) **ABSTRACT**

An apparatus for detecting metrology data in semiconductor packaging processes using fast focus and acquisition techniques to determine alignment metrology data for hybrid bonding. In some embodiments, the apparatus may include a source configured to illuminate a focal point with a wavelength selected from wavelengths greater than 1100 nm, an optical lens that forms an illumination beam when illuminated by the source, an acousto-optic scanner that moves the illumination beam back and forth in a scanning pattern, a splitter to allow the illumination beam to be directed at a metrology sampling location while allowing a reflection beam caused by the illumination beam to pass through the splitter to a detector, a set of optics configured to focus the illumination beam at one or more focal points in a Z direction to obtain subsurface images, and a substrate platform configured to hold a substrate and to move the substrate during scanning.

20 Claims, 4 Drawing Sheets



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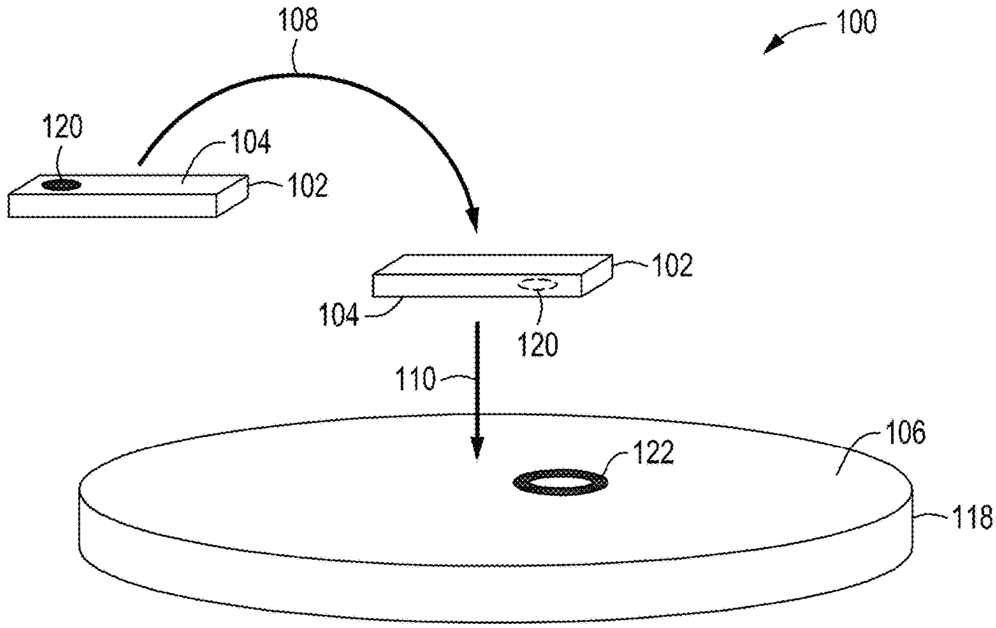

108
100
120
104
102
102
104
120
110
106
122
118

FIG. 1

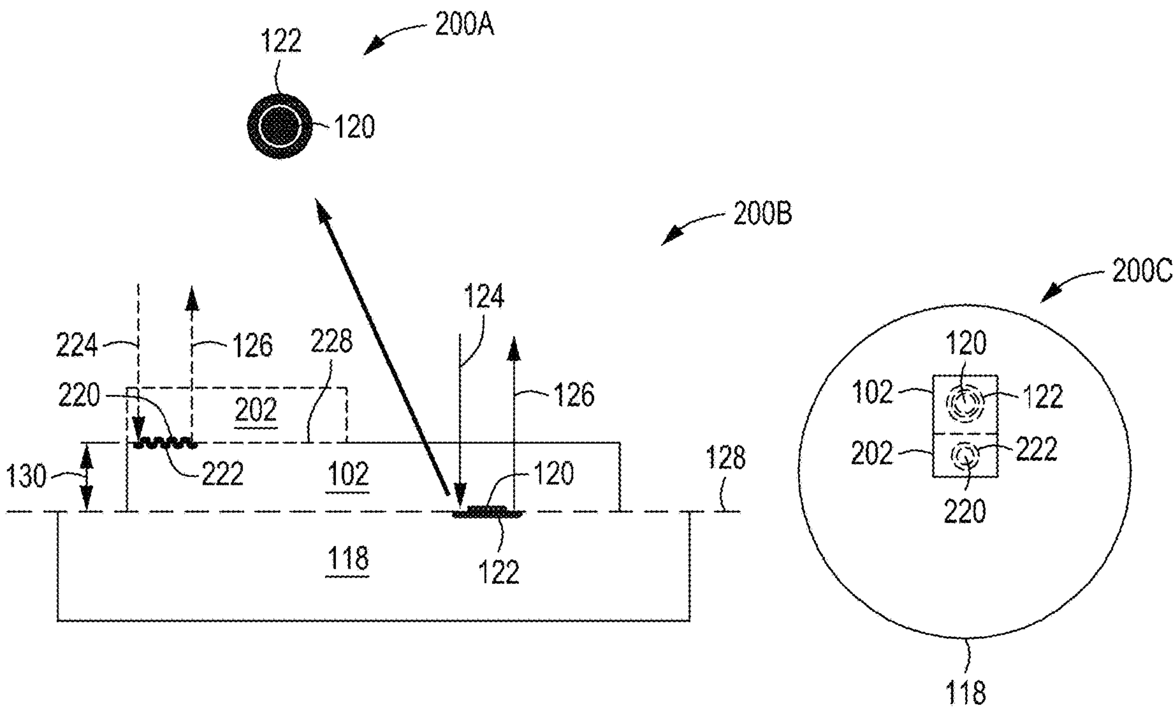
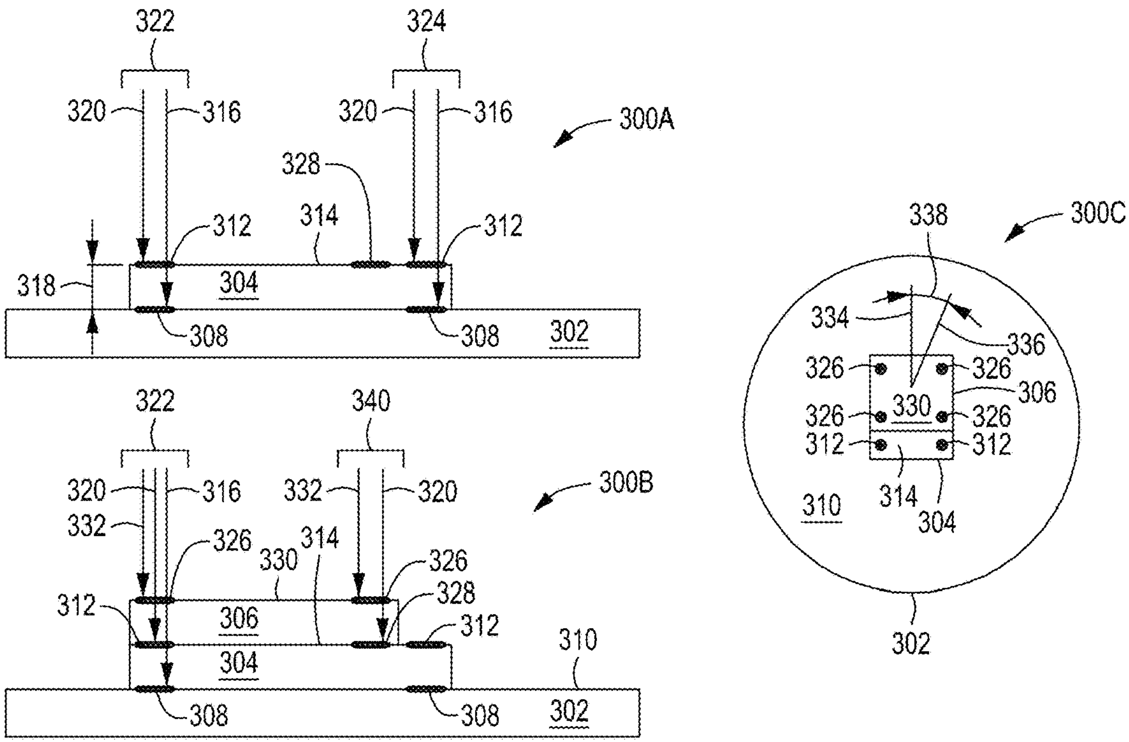
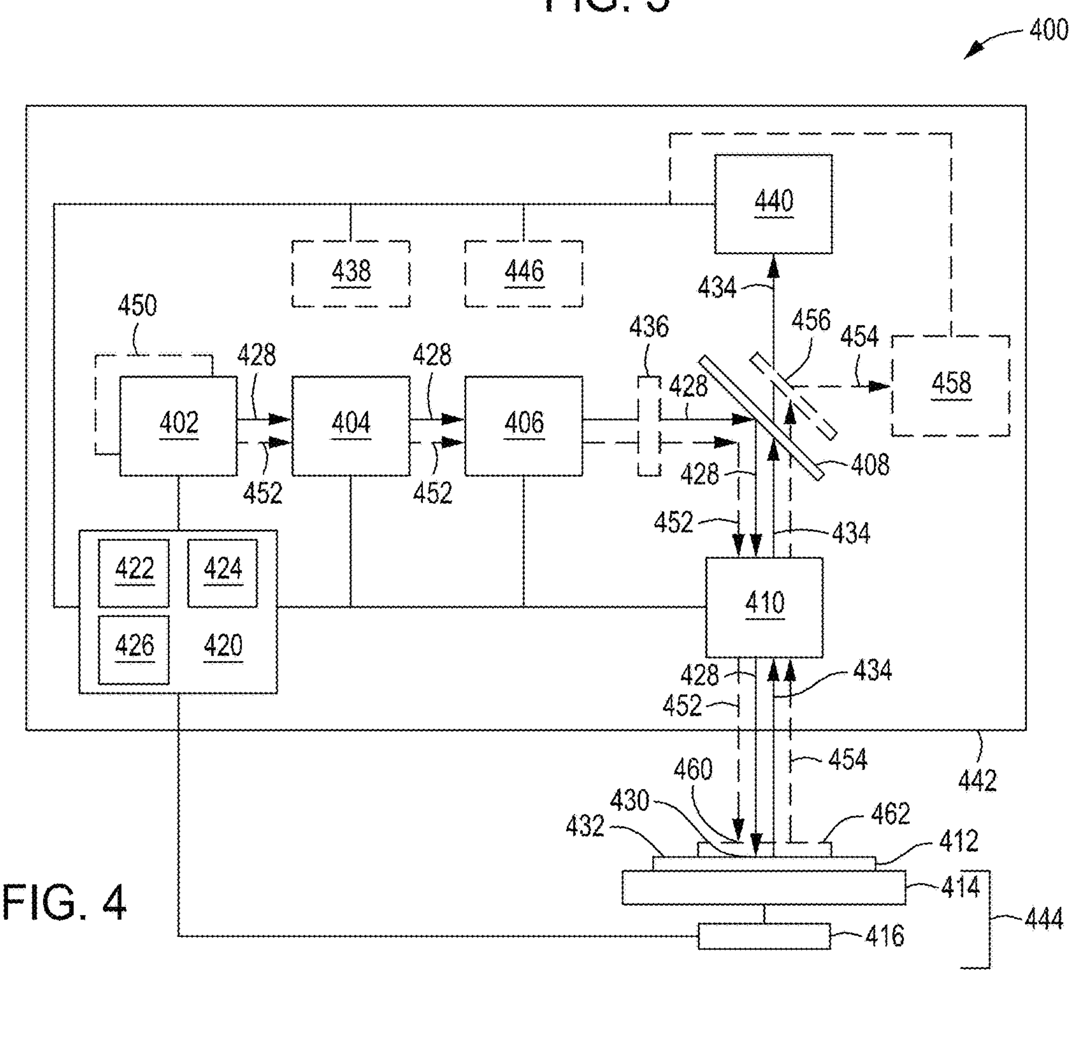

122
200A
120
200B
200C
124
224
126
228
126
120
220
202
102
122
130
222
102
120
128
202
222
118
122
220
118

FIG. 2



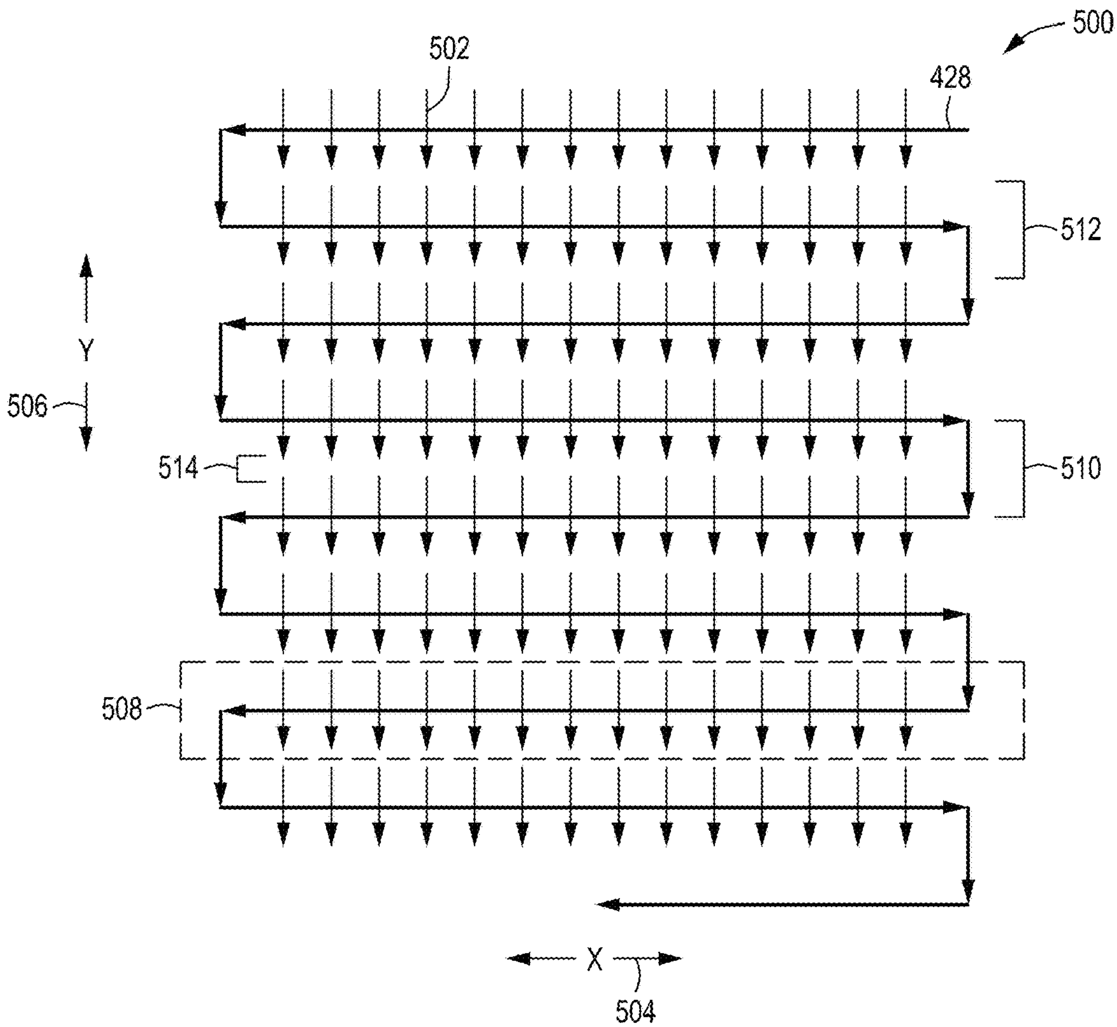
322
324
320
316
300A
328
314
312
318
304
308
302
338
300C
334
336
326
306
330
310
340
332
300B
313
304

FIG. 3



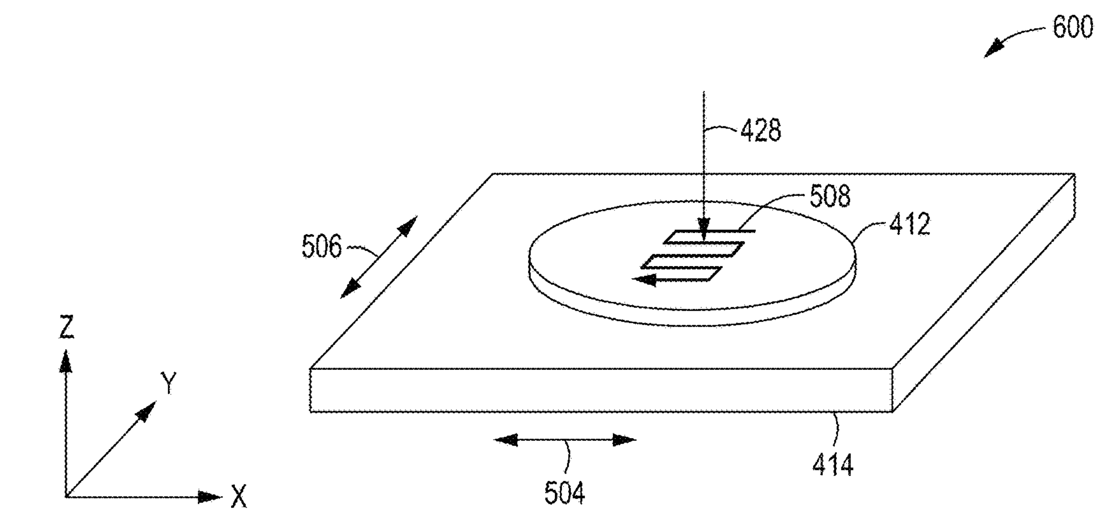
400
440
438
446
434
450
428
456
454
436
458
402
404
406
452
408
422
424
410
426
420
442
460
430
432
462
412
414
444
416

FIG. 4



500
502
428
512
Y
506
514
510
508
X
504

FIG. 5



600
428
508
412
506
Z
Y
X
504
414

FIG. 6

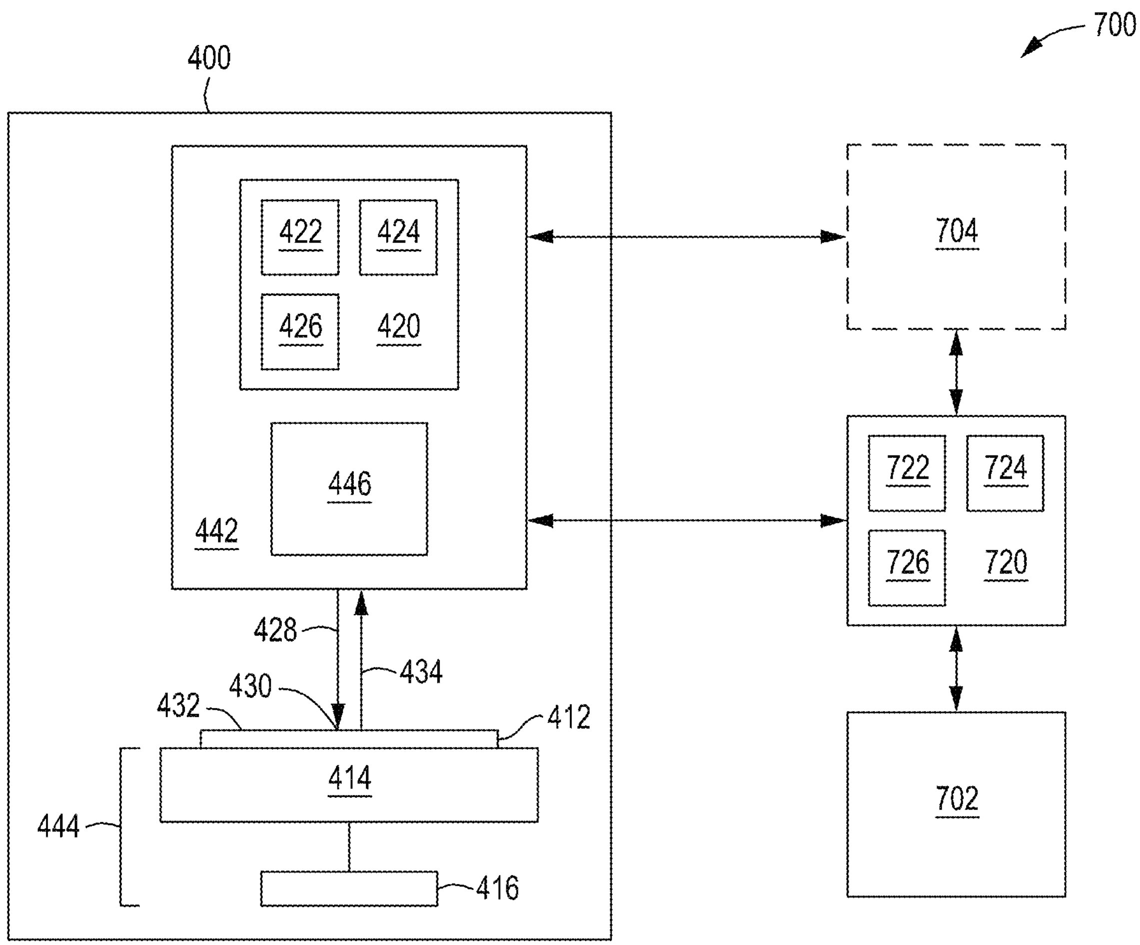

700
400
422
424
426
420
704
446
442
722
724
726
720
428
434
430
432
412
414
444
416
702

FIG. 7

SUBSURFACE ALIGNMENT METROLOGY SYSTEM FOR PACKAGING APPLICATIONS

FIELD

Embodiments of the present principles generally relate to semiconductor processing of semiconductor substrates.

BACKGROUND

During semiconductor manufacturing, aligning of masks is typically accomplished by using systems that step to a location, obtain data from that location, and then move on to the next location. The inventors have observed, however, that in packaging applications, thousands of locations may need to be processed on a single substrate and mechanically based step and repeat systems are not fast enough to process the large number of locations without a substantial impact on throughput.

Accordingly, the inventors have provided methods, apparatus, and systems for alignment metrology conducive to packaging applications.

SUMMARY

Methods, apparatus, and systems for providing alignment metrology for packaging applications are provided herein.

In some embodiments, an apparatus for detecting metrology data may comprise a source using a laser configured to illuminate a focal point through silicon where a wavelength of the source is selected from wavelengths greater than 1100 nm and configured to generate a diffraction-limited focus for subsurface imaging, an optical lens configured to form an illumination beam when illuminated by the source, an acousto-optic scanner configured to move the illumination beam back and forth in a scanning pattern, a splitter configured to allow the illumination beam to be directed at a metrology sampling location while allowing a reflection beam caused by the illumination beam to pass through the splitter to a detector, a set of optics configured to focus the illumination beam at a focal point in a Z direction to obtain subsurface images, and a substrate platform configured to hold a substrate and to move the substrate in an X direction and a Y direction based on a metrology data acquisition pattern where the apparatus is configured to obtain metrology data for a semiconductor packaging process.

In some embodiments, a system for correcting packaging alignment errors may comprise an apparatus for detecting metrology data that may include at least one source using a laser configured to illuminate a focal point through silicon where a wavelength of the source is configured to generate a diffraction-limited focus for subsurface imaging, at least one optical lens configured to form at least one illumination beam when illuminated by the at least one source, at least one scanner configured to move the at least one illumination beam back and forth in a scanning pattern, at least one splitter configured to allow the at least one illumination beam to be directed at a metrology sampling location while allowing at least one reflection beam caused by the at least one illumination beam to pass through the at least one splitter to at least one detector, at least one set of optics configured to focus the at least one illumination beam at one or more focal planes in a Z direction to obtain subsurface images, and a substrate platform configured to hold a substrate and to move the substrate in an X direction and a Y direction based on a metrology data acquisition pattern where the apparatus is configured to obtain metrology data for a semiconductor packaging process, a first controller in communication with the at least one scanner and the at least one set of optics and configured to automatically adjust the scanning pattern and a focus based on an amount of metrology data for a particular location on the substrate, the at least one detector configured to receive the at least one reflection beam and generate subsurface images, an alignment correlator in communication with the at least one detector and configured to determine alignment errors from the subsurface images from the at least one detector, and a second controller in communication with a hybrid bonder and configured to adjust alignment of chips on the substrate based on the alignment errors from the alignment correlator.

In some embodiments, an apparatus for detecting metrology data may comprise a source using a laser configured to illuminate a focal point through silicon where a wavelength of the source is selected from wavelengths greater than 1100 nm and configured to generate a diffraction-limited focus for subsurface imaging, an optical lens configured to form an illumination beam when illuminated by the source, an acousto-optic scanner configured to move the illumination beam back and forth in a scanning pattern, a splitter configured to allow the illumination beam to be directed at a metrology sampling location while allowing a reflection beam caused by the illumination beam to pass through the splitter to a detector, a set of optics configured to focus the illumination beam at one or more focal points in a Z direction to obtain subsurface images where the set of optics includes correction for spherical aberrations caused by the illumination beam passing through at least one surface plane, a substrate platform configured to hold a substrate and to move the substrate in an X direction and a Y direction based on a metrology data acquisition pattern, and a controller in communication with the acousto-optic scanner and the set of optics and configured to automatically adjust the scanning pattern and a focus based on an amount of metrology data for a particular location on the substrate where the apparatus is configured to obtain metrology data for a hybrid bonder in a semiconductor packaging process.

Other and further embodiments are disclosed below.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present principles, briefly summarized above and discussed in greater detail below, can be understood by reference to the illustrative embodiments of the principles depicted in the appended drawings. However, the appended drawings illustrate only typical embodiments of the principles and are thus not to be considered limiting of scope, for the principles may admit to other equally effective embodiments.

FIG. **1** depicts an isometric view of chips bonded to a substrate in accordance with some embodiments of the present principles.

FIG. **2** depicts a cross-sectional view and top-down views of alignment of chips bonded to a substrate in accordance with some embodiments of the present principles.

FIG. **3** depicts cross-sectional views and a top-down view of alignment of chips bonded to a substrate in accordance with some embodiments of the present principles.

FIG. **4** depicts a cross-sectional view of a metrology system in accordance with some embodiments of the present principles.

FIG. **5** depicts a top-down view of a scanning pattern in accordance with some embodiments of the present principles.

FIG. **6** depicts an isometric view of substrate support motion in accordance with some embodiments of the present principles.

FIG. **7** depicts a cross-sectional view of a metrology system in communication with a hybrid bonder to enable alignment feedback in accordance with some embodiments of the present principles.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. The figures are not drawn to scale and may be simplified for clarity. Elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

The methods, apparatus, and systems provide a fast and efficient alignment metrology solution for subsurface alignment of targets that is compatible with the high demands found in packaging applications such as, but not limited to, hybrid bonding and the like. Non-mechanical scanning techniques are employed to allow for quicker data acquisition at each scanning location while providing adjustable data acquisition scans. In critical locations, metrology scanning can be adjusted to obtain high precision (more data) and readjusted in low critical areas to reduce data throughput, decreasing overall data processing demands. Step and repeat type metrology systems are typically based on mechanical mechanisms that are used to scan and obtain data from a surface of a substrate. The acceleration and deceleration of the mechanical mechanism impacts the speed at which the step and repeat type metrology system can obtain data, increasing the overall processing time. The inventors have found that by eliminating the mechanical aspects and employing a non-mechanical scanning apparatus, the data acquisition speed can be significantly enhanced.

An ever-pressing problem in hybrid bonding and packaging applications is the need to ensure precise positioning of bonding pads of two connecting bodies. Although in absolute terms the requirements are not as stringent as requirements needed in usual IC manufacturing, the issue nevertheless poses a significant problem, since the bonding pads are below the top silicon chip, and, thus, not viewable in the visible light range. Infrared is used to allow a metrology station to see through and below a chip to expose alignment marks on the substrate on which the chip has been bonded. To achieve any reasonable throughput, alignment metrology for packaging applications requires fast techniques, approaching thousands of measurements per hour.

Traditional techniques to perform the task of subsurface imaging and alignment have been carried out using high-resolution short-wave IR (SWIR) microscopy in a "step and repeat" imaging system. The step and repeat approach is unacceptably slow as the number of inspection sites increases. The inventors have found that no suitable SWIR cameras exist that can operate in a smooth continuous motion in order to achieve the required throughput needed in packaging applications. SWIR line scan cameras do exist. However, the inventors found that such sensors demand a focused line illumination requiring laser radiation which cannot be used directly due to the generation of unacceptable levels of speckle in the image. The inventors further found that attempts to "speckle-bust" the laser radiation causes the output light to not be focused tightly, thus, negating the possibility of fast and high-resolution imaging.

The inventors discovered a solution to the challenging issues by using a SWIR spot scanning apparatus in a high-resolution, reflection mode to generate subsurface images of the targets (e.g., fiducials, etc.). There are difficulties associated with the appropriate light source or detector that plague the operation of such a system in field or line-imaging mode in the SWIR regime. The inventors found that the difficulties can be overcome for packaging applications when used with single point detectors with adequate performance and laser sources operating at approximately 1100 nm wavelengths and longer that can generate a small, diffraction-limited focus. By incorporating non-mechanical scanning apparatus such as, but not limited to, acousto-optic scanners operating in near-IR, the speed of the scanning is dramatically increased.

The fact that packaging processes require subsurface imaging presents unique challenges compared to other metrology data gathering systems. FIG. **1** depicts an isometric view **100** of a first chip **102** bonded to a substrate **118** in accordance with some embodiments. The first chip **102** typically originates from a component substrate (not shown). During hybrid bonding, the first chip **102** is ejected and picked from the component substrate and flipped **108** upside down such that the top surface **104** of the first chip **102** with a first alignment mark **120** (or fiducial) becomes a bottom surface or chip bonding surface that is bonded to an upper surface **106** or substrate bonding surface of the substrate **118**. The upper surface **106** of the substrate **118** typically has a second alignment mark **122** that is used to align with the first alignment mark **120** of the first chip **102** during bonding **110**. FIG. **2** depicts a cross-sectional view **200**B and a top-down view **200**A of aligned fiducial marks and a top-down view **200**C of the first chip **102** bonded to the substrate **118** in accordance with some embodiments. For the examples depicted in FIGS. **1** and **2** and not meant to be limiting, the first alignment mark **120** on the first chip **102** is a circle and the second alignment mark **122** on the substrate **118** is a ring. For the example, a proper alignment is when the circle of the first alignment mark **120** is centered within the ring of the second alignment mark **122** of the substrate **118** as depicted in top-down view **200**A and top-down view **200**C. When the first chip **102** is bonded to the substrate **118**, the first alignment mark **120** and the second alignment mark **122** are essentially co-planar along plane **128** as depicted in the cross-sectional view **200**B.

To determine if proper alignment of the first chip **102** and the substrate **118** has been accomplished after bonding, a first illumination beam **124** is set to penetrate through the first chip **102** to a depth **130** near the upper surface **106** of the substrate **118** and the bonding surface of the first chip **102** at plane **128**. A first reflection beam **126** is then captured by a detector (not shown, see FIG. **4**) which processes a set of image data from the first reflection beam **126**. The detector or an associated image analyzer (alignment correlator **446** of FIG. **4**) compares the image data of the first alignment mark **120** of the first chip **102** to the second alignment mark **122** of the substrate **118** and determines if an alignment error has occurred. The image data may also be compared to historical image/alignment error data to determine an overall alignment error including rotational errors (angle alignment error caused by rotational skewing of the bonded chip relative to the substrate, see, e.g., FIG. **3**, view **300**C).

Some packaging processes have stacked chips which require multi-planar subsurface imaging which presents unique challenges. For example, the system should be capable of imaging at multiple depths or focal points as needed. In some embodiments, an optional second chip **202** may be bonded to the first chip **102** as depicted in FIG. **2**. A fourth alignment mark **222** of the optional second chip **202** is used to align with a third alignment mark **220** of the first chip **102** during bonding **110**. For the example depicted in FIG. **2** and not meant to be limiting, the third alignment mark **220** on the optional second chip **202** is a circle and the fourth alignment mark **222** on the first chip **102** is a ring. For the example, a proper alignment is when the circle of the third alignment mark **220** is centered within the ring of the fourth alignment mark **222** of the first chip similar to the top-down view **200**A and as depicted in the top-down view **200**C. When the optional second chip **202** is bonded to the first chip **102**, the third alignment mark **220** and the fourth alignment mark **222** are essentially co-planar at the interface **228** of the bonded surfaces of the chips as depicted in the cross-sectional view **200**B.

To determine if proper alignment of the first chip **102** and the second chip **202** has been accomplished after bonding, a second illumination beam **224** is set to penetrate through the optional second chip **202** to a depth of the interface **228** of the chips. A second reflection beam **226** is then captured by a detector (not shown, see FIG. **4**) which processes a set of image data from the second reflection beam **226**. The detector or an associated image analyzer (alignment correlator **446** of FIG. **4**) compares the image data of the third alignment mark **220** of the optional second chip **202** to the fourth alignment mark **222** of the first chip **102** and determines if an alignment error has occurred. The image data may also be compared to historical image/alignment error data to determine an overall alignment error including rotational errors (angle alignment error caused by rotational skewing of the bonded chip relative to the substrate, see, e.g., FIG. **3**, view **300**C).

In more complex packaging processes, bonded single chips and bonded stacked chips may require multi-planar subsurface imaging to obtain fiducial alignment images as the fiducial alignment pairs may be located at different planes. In a cross-sectional view **300**A of FIG. **3**, a first chip **304** has been bonded to a substrate **302**. The substrate **302** has fiducials or a first set of alignment marks **308** on a first surface **310**. The first chip **304** has a second set of alignment marks **312** on a second surface **314** that are meant to align the first chip **304** to the substrate **302**. To determine if proper alignment of the first chip **304** and the substrate **302** has been accomplished after bonding, at a first location **322** on the substrate **302**, a first illumination beam **316** is set to penetrate through the first chip **304** to a first depth **318** near the first surface **310** of the substrate **302**. A first reflection beam (not shown, see FIG. **4**) is then captured by a detector (not shown, see FIG. **4**) which processes a first set of image data from the first reflection beam. A second illumination beam **320** is adjusted such that the second illumination beam **320** reflects off of the second surface **314** and a second reflection beam (not shown) is received by the detector which processes a second set of image data. The detector or an associated image analyzer (alignment correlator **446** of FIG. **4**) compares the sets of image data and determines if an alignment error has occurred. The process then continues to a second location **324** on the substrate **302** and repeated. The image data from the second location **324** may also be compared to the image/alignment error data from the first location **322** to determine an overall alignment error including rotational errors (angle alignment error caused by rotational skewing of the bonded chip).

In a cross-sectional view **300**B of FIG. **3**, a second chip **306** has been bonded to the first chip **304**. The second chip **306** has a third set of alignment marks **326** on a third surface **330** of the second chip **306** that are meant to align the second chip **306** to the first chip **304**. The third set of alignment marks **326** align with a fourth set of alignment marks **328** on the second surface **314** of the first chip **304** at a third location **340** and also one or more of the marks of the second set of alignment marks **312** on the second surface **314** of the first chip **304** at the first location **322**. In cases where alignment overlap occurs in multiple bonding stacks, prior image data can be used to compare with newly acquired image data at a different depth. Given that the first illumination beam **316** produced image data regarding alignment marks of the first set of alignment marks **308** at the first location **322** and also that the second illumination beam **320** produced image data regarding alignment marks of the second set of alignment marks **312** at the first location **322**, a third illumination beam **332** can be used to produce image data regarding the alignment marks of the third set of alignment marks **326** at the first location **322**. The image data from each of the surfaces of the substrate **302**, the first chip **304**, and second chip **306** can be compared for the first location **322** without requiring repeating of the illumination beams at the different depth levels (focal points). In the case of the third location **340**, the illumination beams at the depth of the second surface **314** and the third surface **330** can be repeated for the third location **340** to obtain alignment error data for the third set of alignment marks **326** to the fourth set of alignment marks **328** at the third location **340**.

In a top-down view **300**C of FIG. **3**, the substrate **302** is depicted with the first chip **304** bonded to the substrate **302** and the second chip **306** bonded to the first chip **304**. On the third surface **330** of the second chip **306**, the third set of alignment marks **326** are visible. On the second surface **314** of the first chip **304**, a portion of the second set of alignment marks **312** are visible. As an example, a desired orientation line **334** for the second chip **306** is used to compare with an actual (skewed) orientation line **336** with an error angle **338**. The error angle **338** indicates positive or negative rotation from the desired orientation. Thus, both alignment errors and orientation errors can be determined from the image data obtained from the alignment marks. The illumination source must be able to penetrate through silicon materials while being fast focus adjustable to allow multiple focal points at different depths. In some circumstances, thousands of locations on the substrate **302** are required to be scanned in a timely manner. Despite the challenges presented, the inventors have overcome the obstacles to produce a fast-scanning apparatus with rapid focusing properties that allows metrology data such as bonding alignment data to obtained quickly and efficiently without slowing the packaging processes and substantially impacting yields. In addition, unique issues such as optical aberrations (e.g., spherical aberrations, etc.) caused by illuminating through surfaces are accounted for in the apparatus.

FIG. **4** shows a depiction of a metrology system **400** consisting of an image detection apparatus **442** with an illumination source **402** (e.g., an IR laser source, etc.), beam forming optics **404** to shape the illumination beam **428**, a scanner **406** (e.g., an acousto-optic scanner, a polygon scanner, a galvanometer scanner, etc.), a focusing objective **410** to position and focus the illumination beam **428** at a location on a substrate **412**, and a detector **440** to generate high-resolution, subsurface images of samples through silicon material of the substrate **412** and/or chips, etc. bonded to the substrate **412**. In some embodiments, an acousto-optic scanner is used to enhance the speed and control of the scanning without mechanical apparatus. The acousto-optic scanner may be implemented for maximum scanning speed in a single or dual chirped mode. In some embodiments, a mechanically based scanners such as, but not limited to, galvanometer scanners or polygon scanners can be used when maximum scanning speed is not required. For example, mechanically based scanners may be used with metrology systems having multiple illumination sources and the like. Images are generated by focusing the illumination beam **428** onto a location **430** on a surface **432** of the substrate **412** or on a surface of a chip bonded to the substrate (not shown, see FIGS. **2** and **3**). In some embodiments, additional relay optics and/or magnification changer apparatus **436** may be employed after the scanner **406** and before a splitter **408** (illumination beam splitter or reflection beam splitter).

The scanner **406** moves the illumination beam **428** in a fast scan in one direction while a substrate support **414** is moved by an actuator **416** slowly in an orthogonal direction to the fast scan in a raster fashion. The metrology system **400** also includes a substrate motion apparatus **444** for assisting in the scanning of a substrate/chip. For example, as depicted in a view **500** of FIG. **5**, the illumination beam **428** travels in an X direction slowly while the fast scan **502** scans in an orthogonal direction to the X direction. The interface between the two surfaces of the bonded pieces is scanned in a swath **508**. Multiple swaths are performed which start at the top of the image sample location and finish at the bottom. At the end of the swath **508**, the position of the sample is advanced in the Y direction **506** by a distance **510** less than a width **512** of the swath **508** (in FIG. **5**, the actual width of the swath has been reduced slightly for clarity as the orthogonal scanning arrows of each swath would overlay each other and detail would be lost). The process is repeated by scanning the sample in the opposite direction and so forth. Thus, an overlap **514** of a few pixels between any two adjacent swaths exists to ensure satisfactory imaging of the entire substrate **412**. In some embodiments, as depicted in an isometric view **600** of FIG. **6**, the actuator **416** (see FIG. **4**) of the substrate support **414** moves the substrate **412** slower in an X direction **504** such that the illumination beam **428** forms a swath **508** on a desired location of the substrate **412** (or chip bonded to the substrate **412**). When the swath **508** is completed, the actuator **416** moves the substrate support **414** in a Y direction **506** which is a distance less than the orthogonal scan width (width **512**). The actuator **416** then moves in an opposite X direction so that another swath is formed.

During illumination of a target location with the illumination beam **428**, a reflection beam **434** is produced that is used to form image data. The reflection beam **434** is redirected by the splitter **408** to allow the reflection beam **434** to be received by the detector **440**. The detector **440** receives the reflection beam **434** and generates an image. The detector **440** may operate in conjunction with a store **438** where the images can be stored in a memory and recalled for later alignment comparisons and/or in conjunction with an alignment correlator **446** that receives multiple images from the detector and uses image overlay processes to determine alignment error locations and alignment error values (e.g., alignment shift, alignment rotational errors, etc.). In some embodiments, images are made by the detector **440** by taking greater than the Nyquist number of samples per point spread function (PSF), to render the alignment statistics independent of the precise location of any target. Thus, when assembled, the images of the targets are identical (in terms of information the images convey) to any non-scanning images obtained (such as images taken with a digital camera). The algorithmic strategies employed to perform measurements on the images (such as by the alignment correlator **446**) can, therefore, use similar algorithmic strategies used for still images.

An illumination source used with the metrology system **400** should have a relatively narrow band for point scanning. Broadband light sources such as sources used with step and repeat metrology systems are not compatible with metrology systems of the present principles. Broadband light sources distribute the light energies across a ‘broad band’ of light and do not produce enough light at any frequency to enable efficient and strong light beams needed for the metrology systems of the present principles. In addition, broadband light sources tend to shift the lateral resolution towards the longer wavelengths. The inventors have found that the selected light source should have a wavelength selected from a range of wavelengths greater than 1100 nm with sufficient light penetration into the silicon (or other material being used in chip or substrate, etc.) that produces easily detectable reflected light at a desired focal plane. The deterministic factor is the amount of absorption of the wavelength in a material (e.g., chip or substrate material) which is also influenced by the thickness of the material. For example, shorter wavelengths may be used for thinner materials compared to thicker materials of the same material. For example, if silicon is the predominant material being bonded, a wavelength that is not substantially absorbed by the silicon should be selected (e.g., IR wavelengths). The inventors have found that light sources incorporating light emitting diodes or lasers and the like produce powerful, efficient, narrow band beams sufficient to penetrate the materials used in the semiconductor manufacturing arena.

In some embodiments, multiple illumination sources may be used simultaneously to increase throughput by using different wavelengths focused at different levels or planes. For example, in FIG. **4**, a second illumination source **450** is optionally depicted in the metrology system **400**. The second illumination source **450** produces a second illumination beam **452** that travels a similar path as the illumination beam **428** produced by the illumination source **402** except focused at a different plane **460** of, for example, a stacked chip **462** and the like. The scanner **406** is typically a mechanically based scanner (e.g., galvanometer scanner or polygon scanner, etc.) when used in conjunction with multiple illumination sources. Acousto optic scanners are optimized for single wavelengths and the angle of the acousto optic scanner would need time to shift to be compatible with a second wavelength which would impact throughput. The two different wavelengths would also cause different scanning rates when using the acousto optic scanner. Shifting away from the Bragg angle for a particular frequency would also reduce light reflections back to the detectors. Multiple acousto optical scanners would be needed for multiple illumination sources to avoid the angle adjustment issue, increasing costs and complexity of the metrology system **400**. The second illumination beam **452** induces a second reflection beam **454** which travels back to a second detector **458** via a second splitter **456**. Any number of multiple sets of illumination sources, detectors, splitters, sets of optics, or scanners may be used in the implementation of the metrology system **400**.

The data streams obtained by the metrology system **400** may be analyzed in two stages. In the first stage, the raw data (i.e., the stream of photon counts coming from the detector **440**) are reformed into an image and analyzed to extract overlay parameters. Standard machine vision fiducial recognition algorithms can be used (e.g., image registration and template matching and the like). The second stage of analysis is associated with how the extracted overlay measurements relate to various process tool parameters. For example, sub-optimal parameter tuning in an upstream step may manifest as greater misalignment of coupons towards the edge of the wafer. As another example, location-dependent misalignment can correlate to pressure profiles used during a bonding step in a bonding process. Machine learning can also be used in the context of an integrated packaging tool with on-board metrology capabilities that have the ability to establish relationship types.

In some embodiments, a first controller **420** may be used to enable data collection and feedback from the respective apparatus of the metrology system **400** to optimize performance of the metrology system **400** as well as control of the system apparatus (e.g., scanning patterns, scanning control, scanning locations, etc.). The first controller **420** generally includes a Central Processing Unit (CPU) **422**, a memory **424**, and a support circuit **426**. The CPU **422** may be any form of a general-purpose computer processor that can be used in an industrial setting. The support circuit **426** is conventionally coupled to the CPU **422** and may comprise a cache, clock circuits, input/output subsystems, power supplies, and the like. Software routines, such as a method for controlling the metrology system **400** as described above may be stored in the memory **424** and, when executed by the CPU **422**, transform the CPU **422** into a specific purpose computer (first controller **420**). The software routines may also be stored and/or executed by a second controller (not shown) that is located remotely from the metrology system **400**.

In some embodiments, the first controller **420** may be in communication with the illumination source **402** to alter the illumination wavelength and/or power and the like, the beam forming optics **404** to shape the illumination beam, the scanner **406** to increase or decrease a scanning rate and/or a scanning width, the focusing objective **410** to position and focus the illumination beam at a location on the substrate/chip, and the detector **440** to generate high-resolution images by altering algorithm types and the like. For hybrid bonding applications, precision positioning of the pixels in the obtained images is very important. The first controller **420** enables control over the sweep of the illumination beam via the scanner **406** to obtain precision positioning. The first controller **420** may also be in communication with the store **438** and/or the alignment correlator **446** to further enhance the metrology data gathering process. The first controller **420** may also be in communication with the actuator **416** of the substrate support **414** to enable X direction and Y direction movement to produce scanning swaths as discussed above. The first controller **420** may also alter the scanning locations on the substrate/chip as required by commanding the actuator **416** to move to different locations. The first controller **420** may also communicate with the scanner **406** and the actuator **416** in concert to enable a desired scanning pattern and the like. One skilled in the art will understand that other ancillary apparatus (e.g., additional optics, power sources, etc.) may be used in conjunction with the metrology system **400**, and the first controller **420** may also be in communication with the ancillary apparatus.

The description of the metrology system **400** has been given in conjunction with a single scanning spot architecture. However, multi-spot arrangements can also be used, where the sample (e.g., substrate, chip, etc.) is simultaneously interrogated by many spots. Multi-spot configurations may use trains of chirped acoustic signals in a long scan or may use many short span scanning spots made possible with a diffractive optical element. In such systems, a detector (e.g., detector **440**) is used for each scanning spot. The electronics and computation requirements are more complex, but the throughput of the system goes up proportionally to the number of scanning spots.

The metrology system **400** may be used in conjunction with a hybrid bonder **702** to improve the hybrid bonding alignment process as depicted in a view **700** of FIG. **7**. The hybrid bonder **702** is typically controlled by a third controller **720**. The third controller **720** may be used to enable data collection and feedback/feedforward from the first controller **420** of the metrology system **400** to optimize performance of the hybrid bonder **702**. The third controller **720** generally includes a Central Processing Unit (CPU) **722**, a memory **724**, and a support circuit **726**. The CPU **722** may be any form of a general-purpose computer processor that can be used in an industrial setting. The support circuit **726** is conventionally coupled to the CPU **722** and may comprise a cache, clock circuits, input/output subsystems, power supplies, and the like. Software routines, such as a method for controlling the alignment of bonding substrates and/or chips may be stored in the memory **724** and, when executed by the CPU **722**, transform the CPU **722** into a specific purpose computer (third controller **720**). The software routines may also be stored and/or executed by a fourth controller (not shown) that is located remotely from the hybrid bonder **702**.

In some embodiments, the metrology system **400** may directly communicate with the third controller **720** to relay alignment information to the hybrid bonder **702** such that subsequent bonding processes have improved alignment errors. The feedback/feedforward from the metrology system **400** may be in real-time or at scheduled intervals. In some embodiments, the alignment correlator **446** of the metrology system **400** may transmit actual alignment error data and values such as, but not limited to, alignment offsets for each fiducial and/or an angular rotation error value for a given type of chip and/or the location of the chip or chips. To facilitate in enhancing the value of the alignment information, the metrology system **400** may incorporate machine learning to augment the image data processing in, for example, but not limited to, the detector **440**, the alignment correlator **446**, and/or the first controller **420**. In some embodiments, an alignment image data processor **704** may be used along with machine learning to interpret the alignment information and/or data information from the metrology system **400** in order to correlate the alignment errors to changes required in the hybrid bonder **702** to reduce or eliminate subsequent bonding alignment errors. As such, for example but not limited to, the machine learning may account for alignment shift data, alignment rotational errors, and the like and determine, for example but not limited, the capabilities of the hybrid bonder **702** to reduce/eliminate the errors. For example, the machine learning may account for the hybrid bonder's application pressure, amount of vacuum used to pick up the chips, and/or tolerances of the mechanical apparatus used to position a chip on a substrate and the like in order to decrease alignment errors by the hybrid bonder.

Embodiments in accordance with the present principles may be implemented in hardware, firmware, software, or any combination thereof. Embodiments may also be implemented as instructions stored using one or more computer readable media, which may be read and executed by one or more processors. A computer readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing platform or a "virtual machine" running on one or more computing platforms). For example, a computer readable medium may include any suitable form of volatile or non-volatile memory. In some embodiments, the computer readable media may include a non-transitory computer readable medium.

While the foregoing is directed to embodiments of the present principles, other and further embodiments of the principles may be devised without departing from the basic scope thereof.

The invention claimed is:

1. An apparatus for detecting metrology data, comprising:

a source using a laser configured to illuminate a focal point through silicon, wherein the source uses only a single wavelength that is greater than 1100 nm and configured with sufficient light penetration into the silicon at a desired focal plane within the silicon to generate a diffraction-limited focus for subsurface imaging;

an optical lens configured to form an illumination beam when illuminated by the source;

an acousto-optic scanner configured to move the illumination beam back and forth in a scanning pattern;

a splitter configured to allow the illumination beam to be directed at a metrology sampling location while allowing a reflection beam caused by the illumination beam to pass through the splitter to a detector;

a set of optics configured to focus the illumination beam at a focal point in a Z direction to obtain subsurface images; and

a substrate platform configured to hold a substrate and to move the substrate in an X direction and a Y direction based on a metrology data acquisition pattern,

wherein the apparatus is configured to obtain metrology data for a semiconductor packaging process.

2. The apparatus of claim **1**, wherein the set of optics is further configured to focus at more than one focal point in the Z direction to obtain subsurface images at a plurality of focal planes.

3. The apparatus of claim **1**, wherein the substrate platform is configured to move in an X direction while the acousto-optic scanner moves the illumination beam back and forth to form a scanning swath and is configured to move in the Y direction when a scanning swath is completed.

4. The apparatus of claim **1**, wherein the apparatus is configured with an illumination beam splitter and multiple sets of acousto-optic scanners, splitters, and sets of optics configured to obtain metrology data from multiple locations on the substrate simultaneously.

5. The apparatus of claim **1**, further comprising:

a controller in communication with the acousto-optic scanner and the set of optics and configured to automatically adjust the scanning pattern and a focus based on an amount of metrology data for a particular location on the substrate.

6. The apparatus of claim **1**, wherein the semiconductor packaging process is a hybrid bonder.

7. The apparatus of claim **1**, wherein the set of optics includes correction for spherical aberrations caused by the illumination beam passing through at least one surface plane.

8. The apparatus of claim **1**, wherein the acousto-optic scanner is configured to operate in a dual chirped mode.

9. A system for correcting packaging alignment errors, comprising:

an apparatus for detecting metrology data including:

at least one source using a laser configured to illuminate a focal point through silicon, wherein a wavelength of the source is configured to generate a diffraction-limited focus for subsurface imaging;

at least one optical lens configured to form at least one illumination beam when illuminated by the at least one source;

at least one scanner configured to move the at least one illumination beam back and forth in a scanning pattern;

at least one splitter configured to allow the at least one illumination beam to be directed at a metrology sampling location while allowing at least one reflection beam caused by the at least one illumination beam to pass through the at least one splitter to at least one detector;

at least one set of optics configured to focus the at least one illumination beam at one or more focal planes in a Z direction to obtain subsurface images; and

a substrate platform configured to hold a substrate and to move the substrate in an X direction and a Y direction based on a metrology data acquisition pattern,

wherein the apparatus is configured to obtain metrology data for a semiconductor packaging process;

a first controller in communication with the at least one scanner and the at least one set of optics and configured to automatically adjust the scanning pattern and a focus based on an amount of metrology data for a particular location on the substrate;

the at least one detector configured to receive the at least one reflection beam and generate subsurface images;

an alignment correlator in communication with the at least one detector and configured to determine alignment errors from the subsurface images from the at least one detector; and

a second controller in communication with a hybrid bonder and configured to adjust alignment of chips on the substrate based on the alignment errors from the alignment correlator.

10. The system of claim **9**, wherein the second controller is configured to adjust a pressure of the hybrid bonder based on the alignment errors.

11. The system of claim **9**, wherein the alignment correlator is configured to use machine learning to determine the alignment errors.

12. The system of claim **9**, wherein the second controller is configured to use machine learning to determine adjustments for the hybrid bonder based on the alignment errors.

13. The apparatus of claim **9**, wherein the wavelength of the source is selected from wavelengths greater than 1100 nm.

14. The apparatus of claim **9**, wherein the substrate platform is configured to move in an X direction while the scanner moves the illumination beam back and forth to form a scanning swath and is configured to move in the Y direction when a scanning swath is completed.

15. The apparatus of claim **9**, wherein the apparatus is configured with at least one illumination beam splitter and multiple sets of scanners, splitters, and sets of optics configured to obtain metrology data from multiple locations on the substrate simultaneously.

16. The apparatus of claim **9**, wherein the at least one set of optics includes correction for spherical aberrations caused by the at least one illumination beam passing through at least one surface plane.

17. The apparatus of claim 9, wherein the at least one scanner is an acousto-optic scanner which is configured to operate in a dual chirped mode.

18. An apparatus for detecting metrology data, comprising:

a source using a laser configured to illuminate a focal point through silicon, wherein the source uses only a single wavelength that is greater than 1100 nm and configured with sufficient light penetration into the silicon at a desired focal plane within the silicon to generate a diffraction-limited focus for subsurface imaging;

an optical lens configured to form an illumination beam when illuminated by the source;

an acousto-optic scanner configured to move the illumination beam back and forth in a scanning pattern;

a splitter configured to allow the illumination beam to be directed at a metrology sampling location while allowing a reflection beam caused by the illumination beam to pass through the splitter to a detector;

a set of optics configured to focus the illumination beam at one or more focal points in a Z direction to obtain subsurface images, wherein the set of optics includes correction for spherical aberrations caused by the illumination beam passing through at least one surface plane;

a substrate platform configured to hold a substrate and to move the substrate in an X direction and a Y direction based on a metrology data acquisition pattern; and

a controller in communication with the acousto-optic scanner and the set of optics and configured to automatically adjust the scanning pattern and a focus based on an amount of metrology data for a particular location on the substrate,

wherein the apparatus is configured to obtain metrology data for a hybrid bonder in a semiconductor packaging process.

19. The apparatus of claim 18, wherein the substrate platform is configured to move in an X direction while the acousto-optic scanner moves the illumination beam back and forth to form a scanning swath and is configured to move in the Y direction when a scanning swath is completed.

20. The apparatus of claim 18, wherein the apparatus is configured with an illumination beam splitter and multiple sets of acousto-optic scanners, splitters, and sets of optics configured to obtain metrology data from multiple locations on the substrate simultaneously or wherein the acousto-optic scanner is configured to operate in a dual chirped mode.

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