

LASER PROCESSING METHOD AND LASER PROCESSING APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a laser processing method and a laser processing apparatus for applying a laser beam to a workpiece to process the workpiece.

Description of the Related Art

Laser processing apparatus, for example, are used to process and divide workpieces such as semiconductor wafers. A laser processing apparatus includes a laser oscillator for emitting a pulsed laser beam, a beam condenser for converging the laser beam emitted from the laser oscillator as a converged spot onto a workpiece, and a chuck table disposed below the beam condenser. For processing the workpiece with the pulsed laser beam that has a wavelength absorbable by the workpiece, for example, the workpiece is held on the chuck table. Then, the converged spot of the laser beam is positioned on one of projected dicing lines or streets on the workpiece. The converged spot and the chuck table are relatively moved along the projected dicing line. Therefore, an ablation process using the laser beam is performed on the workpiece along the path of the converged spot on the

workpiece, forming a laser-processed groove in the workpiece.

In the ablation process, it is inspected whether the laser-processed groove has been formed as designed or not. For example, it is inspected whether the position of the converged spot of the laser beam on the workpiece is shifted from a predetermined processing position or not (see, for example, Japanese Patent Laid-open No. JP2016-104491). Moreover, in the ablation process, it may also be inspected in some cases whether the width of the laser-processed groove deviates from a set value or not (see, for example, Japanese Patent Laid-open No. 2017-28030).

Note that there are instances where a pulsed laser beam having a wavelength absorbable by a workpiece is applied to the workpiece, and a beam plasma occurring in an area of the workpiece irradiated with the laser beam is confirmed (see, for example, Japanese Patent Laid-open No. 2017-120820). An image of the processed area is acquired by capturing an image of the beam plasma, and the deviation of the position where the laser beam is applied from a predetermined processing position is measured on the basis of the image. Furthermore, there are cases where a pulsed laser beam having a wavelength

absorbable by a workpiece is applied to the workpiece, and a light-emitting area occurring in an area of the workpiece irradiated with the laser beam is confirmed (see, for example, Japanese Patent Laid-open No. 2018-202468). An image of the processed area is acquired by capturing an image of the light-emitting area, and it is determined whether the shape of the light-emitting area deviates from a predetermined shape or not.

In the image of the area of the workpiece irradiated with the laser beam, the irradiated area is brighter than other areas and used for real-time observation of the manner in which the workpiece is processed by the laser beam. However, even when the laser processing apparatus is not malfunctioning, the irradiated area in the image may have been abruptly changed in shape. Moreover, the position of the irradiated area may have been abruptly shifted from the position where the laser beam is applied. Additionally, in the ablation process, debris tends to be deposited on a glass cover disposed on a lower portion of the beam condenser. When the deposited amount of debris grows as the ablation process proceeds, the irradiated area is likely to vary greatly in a shape and a position.

SUMMARY OF THE INVENTION

In case the shape of the irradiated area in the image is shifted from the predetermined shape, it is possible that the workpiece may not be processed as designed. Furthermore, in case the position of the irradiated area in the image is shifted from the predetermined processing position, devices formed on the workpiece may possibly be damaged. However, since the shape and the position of the irradiate area in the image may have been changed due to abrupt and unexpected factors, it is difficult to decide whether the changes are sudden temporary faults or non-temporary faults. The present invention has been made in view of the above problems. It is therefore an object of the present invention to provide a laser processing method and a laser processing apparatus that make it easy to notice non-temporary faults in a laser processing process.

In accordance with an aspect of the present invention, there is provided a laser processing method of processing a workpiece by applying a pulsed laser beam having a wavelength absorbable by the workpiece to the workpiece, the laser processing method including a holding step of holding the workpiece on a holding table, a processing step of processing the workpiece by applying

the pulsed laser beam to an upper surface of the workpiece held on the holding table, an image capturing step of capturing an image of the upper surface of the workpiece at a predetermined timing in the processing step, thereby acquiring an image of an irradiated area of the upper surface that is irradiated with the pulsed laser beam, a detecting step of detecting at least either one of a size and a position of the irradiated area that is brighter than other areas of the upper surface, in the image acquired in the image capturing step, and a calculating step of repeating the image capturing step and the detecting step in the processing step on a plurality of different areas of the workpiece or performing the image capturing step and the detecting step in the processing step on each of a plurality of the workpieces, and calculating a variation of at least either one of the size and the position of the irradiated area detected in each of the detecting steps.

Preferably, the laser processing method further includes a warning step of issuing a warning when the variation, calculated in the calculating step, of at least either one of the size and the position of the irradiated area exceeds a preset threshold value.

In accordance with another aspect of the present

invention, there is provided a laser processing apparatus for processing a workpiece by applying a pulsed laser beam having a wavelength absorbable by the workpiece to the workpiece, the laser processing apparatus including a holding table for holding the workpiece, an image capturing unit capturing an image of the workpiece held on the holding table, a laser beam applying unit applying the pulsed laser beam, a detecting section for detecting at least either one of a size and a position of an irradiated area of an upper surface of the workpiece which is irradiated with the pulsed laser beam applied by the laser beam applying unit, in the image of the irradiated area captured by the image capturing unit, at a predetermined timing while the workpiece is being processed by the pulsed laser beam applied to the upper surface of the workpiece held on the holding table by the laser beam applying unit, the irradiated area being brighter than other areas of the upper surface of the workpiece, and a calculating section for calculating a variation of at least either one of the size and the position of the irradiated area detected by the detecting section.

In the laser processing method according to the aspect of the invention, an image of the upper surface of

the workpiece is captured at a predetermined timing in the processing step, thereby acquiring an image of an irradiated area of the upper surface that is irradiated with the pulsed laser beam in the image capturing step. Then, in the detecting step, at least either one of the size and the position of the irradiated area that is brighter than other areas of the upper surface is detected in the image acquired in the image capturing step. Further, the image capturing step and the detecting step in the processing step are repeated on a plurality of different areas of the workpiece or the image capturing step and the detecting step in the processing step are performed on each of a plurality of workpieces. Then, a variation of at least either one of the size and the position of the irradiated area detected in each of the detecting steps is calculated in the calculating step. Since the variation of at least either the shapes or positions of irradiated areas is quantitatively assessed in the calculating step, the operator is likely to notice a non-temporary fault in the laser processing operation. Therefore, a fault in the laser processing operation is prevented from being overlooked, thereby preventing the processing quality from becoming poor.

The above and other objects, features and

advantages of the present invention and the manner of realizing them will become more apparent, and the invention itself will best be understood from a study of the following description and appended claims with reference to the attached drawings showing some preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a laser processing apparatus according to a first embodiment of the present invention;

FIG. 2 is a schematic view, partly in block form, illustrating a configurational example of a laser beam applying unit of the laser processing apparatus;

FIG. 3 is a timing chart illustrating the manner in which an image of a wafer is captured;

FIG. 4 is a flowchart of a laser processing method according to the first embodiment;

FIG. 5 is a side elevational view, partly in cross section, of a wafer, etc., in a holding step;

FIG. 6 is a side elevational view, partly in cross section, of the wafer, etc., in a processing step;

FIG. 7 is a schematic view of an image captured in an image capturing step;

FIG. 8 is a graph illustrating the variation of the sizes of irradiated areas;

FIG. 9A is a schematic view of an image where the central line of a projected dicing line and the central line of an irradiated area are aligned with each other;

FIG. 9B is a schematic view of an image where the central line of a projected dicing line and the central line of an irradiated area are not aligned with each other; and

FIG. 10 is a schematic view of an image having two irradiated areas according to a second embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Some preferred embodiments of the present invention will hereinafter be described below with reference to the accompanying drawings. FIG. 1 illustrates perspective view in a laser processing apparatus 2 according to a first embodiment of the present invention. In FIG. 1, some of the components of the laser processing apparatus 2 are illustrated in functional block form. The laser processing apparatus 2 processes a wafer 11, i.e., a workpiece, mainly made of a semiconductor material such as silicon. The wafer 11 is of a disk shape and has a

thickness ranging from approximately 10 μm to 800 μm , for example, between a face side 11a and a reverse side 11b. The wafer 11 is not limited to any material, shape, structure, size, etc. For example, the wafer 11 may be mainly made of any of semiconductor materials other than silicon, e.g., gallium arsenide (GaAs), silicon carbide (SiC), or the like, or glass, resin, ceramic, or the like. The wafer 11 may not be of a disk shape.

The wafer 11 has a plurality of projected dicing lines or streets 13 (see FIG. 5, etc.) established thereon by which the face side 11a is demarcated into a plurality of areas where devices 15 such as integrated circuits (ICs), or large-scale-integration (LSI) circuits are disposed. The devices 15 include on outermost surfaces thereof respective key patterns 27 (see FIGS. 9A, 9B, or the like) also called "target patterns" or "alignment marks." The wafer 11 is surrounded by an annular frame 17 of metal that has a circular opening defined therein that is larger in diameter than the wafer 11. The wafer 11 is disposed in the circular opening in the annular frame 17. A protective tape 19 that is substantially circular in shape is affixed to a lower surface of the annular frame 17 and the reverse side 11b of the wafer 11. The protective tape 19 is larger in

diameter than the circular opening in the annular frame 17.

The protective tape 19 is in the form of a film of resin and has a layered structure including an adhesive layer, not illustrated, that is sticky and a base layer, not illustrated, that is not sticky. The adhesive layer is an ultraviolet-curable resin layer, for example, and is disposed on an entire surface of the base layer of resin. The adhesive layer of the protective tape 19 is held in intimate contact with and affixed to the reverse side 11b of the wafer 11 and a circumferential lower surface portion of the annular frame 17, making up a wafer unit 21 where the wafer 11 is supported on the annular frame 17 by the protective tape 19.

The laser processing apparatus 2 includes a base table 4 substantially in the form of a rectangular parallelepiped on which various components of laser processing apparatus 2 are mounted. A chuck table 6, i.e., a holding table, for holding the wafer unit 21 is mounted on an upper surface of the base table 4. A horizontal moving mechanism 8, i.e., a processing feed unit and an indexing feed unit, for moving the chuck table 6 in X-axis direction, i.e., processing feed direction, and Y-axis direction, i.e., indexing feed direction, is

disposed on the base table 4 beneath the chuck table 6. The X-axis direction and the Y-axis direction represent horizontal direction.

The horizontal moving mechanism 8 includes a pair of X-axis guide rails 10 fixedly mounted on the upper surface of the base table 4 and extending generally parallel to the X-axis direction, and an X-axis movable table 12 slidably mounted on the X-axis guide rails 10. The X-axis movable table 12 has a nut, not illustrated, mounted on a reverse side, i.e., a lower surface, thereof. An X-axis ball screw 14 extending generally parallel to the X-axis guide rails 10 is rotatably threaded through the nut.

An X-axis stepping motor 16 is coupled to an end of the X-axis ball screw 14. When the X-axis stepping motor 16 is energized, it rotates the X-axis ball screw 14 about its central axis, moving the X-axis movable table 12 in the X-axis direction along the X-axis guide rails 10. The horizontal moving mechanism 8 also includes a pair of Y-axis guide rails 18 fixedly mounted on a face side, i.e., an upper surface, of the X-axis movable table 12 and extending generally parallel to the Y-axis direction, and a Y-axis movable table 20 slidably mounted on the Y-axis guide rails 18.

The Y-axis movable table 20 has a nut, not illustrated, mounted on a reverse side, i.e., a lower surface, thereof. A Y-axis ball screw 22 extending generally parallel to the Y-axis guide rails 18 is rotatably threaded through the nut. A Y-axis stepping motor 24 is coupled to an end of the Y-axis ball screw 22. When the Y-axis stepping motor 24 is energized, it rotates the Y-axis ball screw 22 about its central axis, moving the Y-axis movable table 20 in the Y-axis direction along the Y-axis guide rails 18.

A table mount 26 is mounted on a face side, i.e., an upper surface, of the Y-axis movable table 20. The chuck table 6 is disposed on an upper portion of the table mount 26 with a cover 28 interposed therebetween. The chuck table 6 has an upper surface as a holding surface 6a for holding the wafer 11 thereon. The holding surface 6a includes a disk-shaped porous member as part thereof. The porous member is held in fluid communication with a suction source, not illustrated, such as an ejector through a suction channel, not illustrated, defined in the chuck table 6.

When the suction source is actuated, it generates a negative pressure that is transmitted through the suction channel and acts on an upper surface of the porous member,

i.e., part of the holding surface 6a. In case the wafer unit 21 is placed on the holding surface 6a with the protective tape 19 contacting the holding surface 6a, the negative pressure thus acting on the holding surface 6a holds the reverse side 11b of the wafer 11 on the holding surface 6a. Four clamp units 6b for securing the frame 17 at four locations thereon are disposed around the holding surface 6a. A rotary actuator, not illustrated, is operatively coupled to the table mount 26. The chuck table 6 is rotatable about its central axis generally parallel to Z-axis direction, i.e., vertical direction, perpendicular to the X-axis direction and the Y-axis direction.

A support structure 30 is disposed on a region of the upper surface of the base table 4 that is different from the region where the horizontal moving mechanism 8 is disposed. The support structure 30 has a columnar post 30a and an arm 30b extending in the Y-axis direction in overhanging relation to the horizontal moving mechanism 8 provided on the upper end of the columnar post 30a. A laser beam applying unit 32 is mounted on the arm 30b. The laser beam applying unit 32 has a beam condenser 32a for applying a laser beam to the wafer 11 held under suction on the chuck table 6. The beam condenser 32a is

positioned on a distal end portion of the arm 30b.

A first camera unit 34 for capturing an image of the wafer 11 held on the chuck table 6, etc. is mounted on the arm 30b at a position adjacent to the beam condenser 32a. The first camera unit 34 is used in adjusting the positions of the wafer 11 and the laser beam applying unit 32, i.e., aligning them with each other, for example. Details of the laser beam applying unit 32 will be described below with reference to FIG. 2. FIG. 2 schematically illustrates, partly in block form, a configurational example of the laser beam applying unit 32. Note that, in FIG. 2, some of the components of the laser beam applying unit 32 are illustrated as functional blocks. Furthermore, although the frame 17 and the protective tape 19 are omitted from illustration in FIG. 2, the reverse side 11b of the wafer 11, whose face side 11a is exposed upwardly, is held on the holding surface 6a with the protective tape 19 interposed therebetween.

The laser beam applying unit 32 has a laser beam generator 36. The laser beam generator 36 has a laser oscillator 38 for emitting a pulsed laser beam. The laser oscillator 38 includes a laser medium of Nd : YAG, Nd : YVO₄, or the like suitable for laser oscillation. A repetitive frequency setting unit 40 for setting a

repetition frequency for the pulses of the pulsed laser beam is connected to the laser oscillator 38. The pulsed laser beam, denoted by L, emitted from the laser beam generator 36 has a wavelength that can be absorbed by the wafer 11, for example.

In case the wafer 11 is mainly made of silicon, the wavelength that is absorbable by the wafer 11 is 355 nm, for example. The pulsed laser beam L has a repetitive frequency of 50 kHz, for example, and an average output power of 3.0 W, for example. Note that the laser beam generator 36 also has a wavelength converter, not illustrated, for converging the wavelength of the pulsed laser beam emitted from the laser oscillator 38, a pulse width adjuster, not illustrated, for adjusting the pulse width of the pulsed laser beam, and a power adjuster, not illustrated, for adjusting the output power of the pulsed laser beam.

A dichroic mirror 42 is disposed in the vicinity of the laser beam generator 36. The dichroic mirror 42 reflects light having the wavelength, e.g., 355 nm, of the pulsed laser beam L, but transmits lights in other wavelength bands therethrough. The beam condenser 32a is disposed beneath the dichroic mirror 42. The beam condenser 32a includes a condensing lens 32b converging

the pulsed laser beam L onto the face side 11a, i.e., an upper surface, of the wafer 11.

The pulsed laser beam L emitted from the laser beam generator 36 is reflected by the dichroic mirror 42 and converged by the condensing lens 32b as a converged spot onto the face side 11a of the wafer 11. The converged spot of the pulsed laser beam L applied to the wafer 11 processes the wafer 11 according to an ablation process, for example. The laser beam applying unit 32 further includes a strobe light applying unit 50 in addition to the laser beam generator 36. The strobe light applying unit 50 has a strobe light source 52 for emitting flashes of white light. The strobe light source 52 may be a xenon flash lamp, for example.

The strobe light source 52 periodically emits flashes of white light at intervals of 100 μ s, for example. The flash light emitted from the strobe light source 52 travels through an aperture stop 54 to a collimator lens 56. The aperture stop 54 adjusts the amount of flash light applied from the strobe light source 52 to the collimator lens 56. The collimator lens 56 converts the light from the aperture stop 54 into parallel-ray light. The strobe light applying unit 50 also includes a mirror 58 disposed on a downstream side

of the collimator lens 56 remotely from the aperture stop 54. The light from the collimator lens 56 is reflected by the mirror 58 to travel toward the dichroic mirror 42.

A beam splitter 60 is disposed between the mirror 58 and the dichroic mirror 42. The beam splitter 60 transmits part of the light reflected by the mirror 58 toward the dichroic mirror 42. The light that has passed through the dichroic mirror 42 travels through the condensing lens 32b and is applied to the face side 11a of the wafer 11. Light that is reflected by the face side 11a of the wafer 11 travels through the dichroic mirror 42 to the beam splitter 60. The beam splitter 60 reflects part of the light from the dichroic mirror 42 to travel to a second camera unit 62, i.e., an image capturing unit.

The second camera unit 62 includes a lens unit 64 having an aberration correcting lens 64a and a focusing lens 64b. The lens unit 64 guides the light from the beam splitter 60 onto an image capturing element 66 such as a complementary-metal-oxide-semiconductor (CMOS) image sensor, or a charge-coupled-device (CCD) image sensor. Then, the image capturing element 66 converts the applied light into an electric signal representing information for producing an image. The image capturing element 66 outputs the information for producing an image to a

control unit 70, to be described later. The light that is detected by the image capturing element 66 will be described below with reference to FIG. 3.

FIG. 3 is a timing chart illustrating the manner in which an image of the wafer 11 is captured. The horizontal axis of the timing chart represents time (μs). In case the repetitive frequency of the pulsed laser beam L emitted from the laser beam applying unit 32 is 50 kHz, as described above, a pulse, denoted by Ls in FIG. 3, of the pulsed laser beam L is applied to the wafer 11 per 20 μs . Furthermore, the strobe light source 52 is applied to the wafer 11 at timings different from the timings at which the pulsed laser beam L is applied. Specifically, the strobe light according to the embodiment is initially applied to the wafer 11 at a timing of 50 μs and then periodically applied to the wafer 11 per 100 μs . In FIG. 3, the pulses of strobe light are denoted by St.

The second camera unit 62 includes a shutter, not illustrated, that is opened and closed at suitable timings that are controlled to adjust timings to capture images and periods during which to capture images, etc. According to the present embodiment, immediately before strobe light is emitted at each given timing, the shutter is opened, and then remains open for a predetermined

period ranging from 50 to 70 μ s, for example, to apply the strobe light to the image capturing element 66, which captures an image. Note that, in FIG. 3, the period during which to capture an image is denoted by t. The second camera unit 62 thus acquires an image of light, i.e., plasma light, produced in an area of the wafer 11 where the pulsed laser beam L is applied when the pulsed laser beam L processes part of the wafer 11 according to an ablation process. Note that the acquired image includes a projected dicing line 13 illuminated by the strobe light and a surrounding area, for example, a key pattern to be described later. In this manner, the second camera unit 62 acquires an image including light emitted in the area of the wafer 11 where the pulsed laser beam L is applied, reflected light from the strobe light, etc. at a predetermined timing while the wafer 11 is being processed.

Referring back to FIG. 1, other components of the laser processing apparatus 2 will be described below. The laser processing apparatus 2 includes the control unit 70. The control unit 70 controls operation of various components including the horizontal moving mechanism 8, the laser beam applying unit 32, the first camera unit 34, etc. for appropriately processing the wafer 11. The

control unit 70 may be a computer, for example, having a central processing unit (CPU), a read only memory (ROM), a random access memory (RAM), a hard disk drive, an input/output apparatus, etc. that are connected to each other through a host controller. The CPU performs arithmetic processing operations on the basis of programs, data, or the like stored in storage areas of the ROM, the RAM, the hard disk drive, or the like.

When the CPU reads the programs stored in the storage areas, the control unit 70 functions as specific means where software and hardware means cooperate with each other. The control unit 70 has a detecting section 72 provided by a program stored in the storage areas, for example. The detecting section 72 is, for example, an image processor for detecting edges of an image obtained by the second camera unit 62. The detecting section 72 measures the length in predetermined direction of a target to be measured and additionally calculates coordinates of edges of the target to be measured. Therefore, at least either one of the size and the position of an irradiated area 25 (see FIG. 7) that is irradiated with the pulsed laser beam L in an image is detected by the detecting section 72.

The irradiated area 25 is an area brighter than

other areas in an image acquired by the second camera unit 62. Note that, in case the bright and dark areas of an acquired image are inverted, the irradiated area 25 may be displayed as a dark area. Even in such a case, the detecting section 72 detects the irradiated area 25 without a fail. The control unit 70 further includes a calculating section 74 provided by a program stored in the storage areas, for example. The calculating section 74 calculates, according to a predetermined function, a variation of at least either one of the size and the position of an irradiated area 25 detected by the detecting section 72 with respect to a plurality of different areas of the wafer 11.

The laser processing apparatus 2 has a monitor, not illustrated, that may be a touch-panel monitor. The monitor functions as an input unit accepting inputs from the operator and a display unit displaying processing conditions, processed results, etc. Note that the monitor is also arranged to display a warning about the occurrence of a malfunction or the like in the event that the laser processing apparatus 2 malfunctions. The laser processing apparatus 2 further has a speaker and a warning lamp, both not illustrated. In the event of a malfunction of the laser processing apparatus 2, the

speaker produces a warning sound and the warning lamp blinks.

Next, a laser processing method for performing an ablation process on the wafer 11 on the laser processing apparatus 2 will be described below. FIG. 4 is a flowchart of the laser processing method according to the first embodiment. In the laser processing method according to the first embodiment, the wafer unit 21 is placed on the holding surface 6a with the face side 11a of the wafer 11 being exposed upwardly. Then, the suction source is actuated to hold the reverse side 11b of the wafer 11 under suction on the holding surface 6a in holding step S10. FIG. 5 illustrates in side elevation, partly in cross section, the wafer 11, etc. in holding step S10.

Next, the chuck table 6 is positioned directly below the beam condenser 32a. The wafer 11 and the laser beam applying unit 32 are aligned with each other using the first camera unit 34. In the alignment, the rotary actuator and the horizontal moving mechanism 8 are operated to orient one of the projected dicing lines 13 parallel to the X-axis direction. Then, the converged spot of the pulsed laser beam L is positioned on the projected dicing line 13 on the face side 11a, and the

chuck table 6 is moved in the X-axis direction at a predetermined processing feed speed of 100 mm/s, for example.

Therefore, the pulsed laser beam L is now applied to the face side 11a along the path of the converged spot, performing an ablation process on the wafer 11 along the projected dicing line 13 in processing step S20. FIG. 6 illustrates in side elevation, partly in cross section, the wafer 11, etc., in processing step S20. According to the present embodiment, at a predetermining timing in processing step S20, the second camera unit 62 captures an image of the face side 11a. For example, the second camera unit 62 captures an image of the face side 11a once on one projected dicing line 13. The second camera unit 62 thus captures an image of the irradiated area 25 on the face side 11a where the pulsed laser beam L is applied and acquires the image in image capturing step S30.

FIG. 7 schematically illustrates the image obtained in image capturing step S30. In the illustrated image, a processed trace 23 corresponding to the path of the converged spot is displayed. However, the processed trace 23 may not necessarily be displayed depending on the way in which the image is captured. The irradiated area 25

irradiated with the pulsed laser beam L exists, as displayed relatively brightly, substantially centrally in the image. The extent of a plasma light emission area that occurs due to the application of the pulsed laser beam L corresponds to the extent of the irradiated area 25 irradiated with the pulsed laser beam L.

The irradiated area 25 according to the present embodiment is wider in the Y-axis direction than in the X-axis direction, i.e., is a slender area. According to the present embodiment, the detecting section 72 detects either one of the size and the position of the irradiated area 25 in detecting step S40. After the pulsed laser beam L has been applied to the wafer 11 along the projected dicing line 13, the horizontal moving mechanism 8 moves the chuck table 6 in one of the Y-axis direction, thereby positioning the beam condenser 32a directly above another projected dicing line 13 adjacent to the projected dicing line 13 referred to above in the Y-axis direction.

Then, processing step S20, image capturing step S30, and detecting step S40 are carried out in the same manner as described above. In this manner, processing step S20, image capturing step S30, and detecting step S40 are performed on all the projected dicing lines 13 along the

X-axis direction, after which the rotary actuator is operated to turn the chuck table 6 about its central axis through 90 degrees. Thereafter, processing step S20, image capturing step S30, and detecting step S40 are similarly performed on all the projected dicing lines 13 along the X-axis direction. Image capturing step S30 and detecting step S40 in processing step S20 are thus repeated on a plurality of areas of the wafer 11.

The calculating section 74 calculates a variation of either one of the size and the position of the irradiated area 25 detected in each detecting step S40 in calculating step S50. Note that the timing at which to perform calculating step S50 is appropriately established depending on the kind of the workpiece, the processing conditions, etc. First, an example in which a variation of the size of the irradiated area 25 in calculating step S50 will be described below. FIG. 8 is a graph illustrating the variation of the sizes of irradiated areas 25. The horizontal axis of the graph represents the sequence by which irradiated areas 25 are acquired, the sequence corresponding to the time that has elapsed from the start of the processing operation. The vertical axis of the graph represents the dimensions in the longitudinal direction of the irradiated areas 25, i.e.,

sizes (μm), in direction perpendicular to the longitudinal direction of the projected dicing line 13 being processed, i.e., the Y-axis direction.

In the present example, a standard deviation s is calculated each time the size in the longitudinal direction of the irradiated area 25, hereinafter referred to as the size of the irradiated area 25, is measured, with respect to twenty irradiated areas 25. The standard deviation s is represented by the following equation 1, [Math. 1]

$$s = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2}$$

where i and n are natural numbers, i representing the turn of the acquired irradiated area 25, n representing the total number of acquired irradiated areas 25, x_i is the size of the i th acquired irradiated area 25, and $\bar{x}$ is an average value from x_1 to x_n .

According to the present example, in case $n = 20$, $s = 0.19$. In case $n = 40$, $s = 0.21$, and in case $n = 60$, $s = 0.28$. According to the present example, therefore, the standard deviation s is gradually increased as the measurement went on. In other words, as the processing time elapses, the variation of the sizes of the

irradiated areas 25 increases. Since the variation of the shapes of irradiated areas 25 is quantitatively assessed in calculating step S50, the operator is likely to notice a non-temporary fault in the laser processing operation. Therefore, a fault in the laser processing operation is prevented from being overlooked, thereby preventing the processing quality from becoming poor. Note that the variation of the sizes of irradiated areas 25, i.e., the graph illustrated in FIG. 8, may be displayed on the monitor of the laser processing apparatus 2.

Inasmuch as the variation of the sizes of irradiated areas 25 tends to increase as the processing time goes by, a threshold value for the variation may be preset. In this case, when the variation of the sizes of irradiated areas 25 calculated in calculating step S50 exceeds a preset threshold value, the laser processing apparatus 2 issues a warning such as a warning display, a warning sound, or lamp blinking in warning step S60. Therefore, the operator is now able to clearly grasp a fault of the laser processing apparatus 2. In case the laser processing apparatus 2 issues a warning, the operator shuts off the laser processing apparatus 2 and takes emergency action by, for example, removing debris deposited on the beam condenser 32a. Furthermore, the

operator should preferably make efforts to identify the cause of the fault.

Next, an example in which a variation of the position of the irradiated area 25 is calculated in calculating step S50 will be described below. FIG. 9A schematically illustrates an image where the central line 13a of a projected dicing line 13 and the central line 25a of an irradiated area 25 are aligned with each other. Note that the central line 13a of the projected dicing line 13 is detected by the detecting section 72 on the basis of a pattern of metal or the like having a predetermined geometrical shape on a corner of the device 15 as viewed in plan, i.e., a key pattern 27, for example.

FIG. 9B schematically illustrates an image where the central line 13a of a projected dicing line 13 and the central line 25a of an irradiated area 25 are not aligned with each other. The Y coordinate of the central line 25a illustrated in FIG. 9B is shifted from the Y coordinate of the central line 13a by a distance d in the Y-axis direction. With respect to the Y coordinate of the central line 25a, the calculating section 74 calculates a standard deviation s according to the equation 1 except that y_i representing the Y coordinate of the central line 25a is used instead of x_i in the equation 1, and an

average value from y_1 to y_n is used instead of the average value from x_1 to x_n .

In this manner, since the variation of the positions of irradiated areas 25, i.e., the Y coordinates of the central lines 25a, is quantitatively assessed in calculating step S50, the operator is likely to notice a non-temporary fault in the laser processing operation. Therefore, a fault in the laser processing operation can be prevented from being overlooked, thereby preventing the processing quality from becoming poor. The variation of the positions of irradiated areas 25 obtained in calculating step S50 may be displayed on the monitor of the laser processing apparatus 2. Furthermore, a threshold value for the variation of the positions of irradiated areas 25 may be preset. In this case, when the variation of the positions of irradiated areas 25 calculated in calculating step S50 exceeds a preset threshold value, the laser processing apparatus 2 issues a warning such as a warning display, a warning sound, or lamp blinking in warning step S60.

Therefore, the operator is now able to clearly grasp a fault of the laser processing apparatus 2. In calculating step S50 and warning step S60, both or either one of variation of the sizes of irradiated areas 25 and

the variation of the positions of irradiated areas 25 may be used. According to the first embodiment described above, one image is captured of one projected dicing line 13, and one irradiated area 25 is detected on one projected dicing line 13. However, one image may be captured of one projected dicing line 13, and a plurality of irradiated areas 25 may be detected on one projected dicing line 13. FIG. 10 schematically illustrates an image having two irradiated areas 25 according to a second embodiment of the present invention.

According to the second embodiment, pulsed laser beams L are simultaneously applied to one projected dicing line 13 at two different locations thereon, and two irradiated areas 25 are detected on the projected dicing line 13. For example, the pulsed laser beam L emitted from the laser beam applying unit 32 may be branched into two laser beams for simultaneously processing one projected dicing line 13 at two different locations thereon. According to the second embodiment, the laser processing method from holding step S10 to warning step S60 is carried out to quantitatively assess the variation of at least either the sizes or positions of irradiated areas 25. Consequently, the operator is likely to notice a non-temporary fault in the laser

processing operation. Therefore, a fault in the laser processing operation is prevented from being overlooked, thereby preventing the processing quality from becoming poor.

Next, a third embodiment of the present invention will be described below. According to the third embodiment, image capturing step S30 and detecting step S40 in processing step S20 are carried out once on one wafer 11. However, by performing image capturing step S30 and detecting step S40 in processing step S20 on a plurality of wafers 11, the variation of at least either the sizes or positions of irradiated areas 25 is calculated in calculating step S50. According to the third embodiment, the operator is also likely to notice a non-temporary fault in the laser processing operation. Therefore, a fault in the laser processing operation is prevented from being overlooked, thereby preventing the processing quality from becoming poor.

The structures, methods, etc. according to the above embodiments may be changed or modified without departing from the scope of the invention. For example, the index of variation used in calculating step S50 is not limited to the standard deviation s . A dispersion obtained by squaring the standard deviation s or other

indices may also be used.

The present invention is not limited to the details of the above described preferred embodiments. The scope of the invention is defined by the appended claims and all changes and modifications as fall within the equivalence of the scope of the claims are therefore to be embraced by the invention.

WHAT IS CLAIMED IS:

1. A laser processing method of processing a workpiece by applying a pulsed laser beam having a wavelength absorbable by the workpiece to the workpiece, the laser processing method comprising:

a holding step of holding the workpiece on a holding table;

a processing step of processing the workpiece by applying the pulsed laser beam to an upper surface of the workpiece held on the holding table;

an image capturing step of capturing an image of the upper surface of the workpiece at a predetermined timing in the processing step, thereby acquiring an image of an irradiated area of the upper surface that is irradiated with the pulsed laser beam;

a detecting step of detecting at least either one of a size and a position of the irradiated area that is brighter than other areas of the upper surface, in the image acquired in the image capturing step; and

a calculating step of repeating the image capturing step and the detecting step in the processing step on a plurality of different areas of the workpiece or performing the image capturing step and the detecting step in the processing step on each of a plurality of the

workpieces, and calculating a variation of at least either one of the size and the position of the irradiated area detected in each of the detecting steps.

2. The laser processing method according to claim 1, further comprising:

a warning step of issuing a warning when the variation, calculated in the calculating step, of at least either one of the size and the position of the irradiated area exceeds a preset threshold value.

3. A laser processing apparatus for processing a workpiece by applying a pulsed laser beam having a wavelength absorbable by the workpiece to the workpiece, the laser processing apparatus comprising:

a holding table for holding the workpiece;

an image capturing unit capturing an image of the workpiece held on the holding table;

a laser beam applying unit applying the pulsed laser beam;

a detecting section for detecting at least either one of a size and a position of an irradiated area of an upper surface of the workpiece which is irradiated with the laser beam applied by the laser beam applying unit, in the image of the irradiated area captured by the image capturing unit, at a predetermined timing while the

workpiece is being processed by the pulsed laser beam applied to the upper surface of the workpiece held on the holding table by the laser beam applying unit, the irradiated area being brighter than other areas of the upper surface of the workpiece; and

a calculating section for calculating a variation of at least either one of the size and the position of the irradiated area detected by the detecting section.