

LASER PROCESSING APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a laser processing apparatus for processing a workpiece held on a chuck table by applying thereto a laser beam whose wavelength is transmittable through the workpiece while positioning a focused point of the laser beam within the workpiece, thereby forming modified layers in the workpiece.

Description of the Related Art

Wafers where a plurality of devices such as integrated circuits (ICs), or large scale integration (LSI) are formed in respective areas thereof demarcated by a plurality of intersecting projected dicing lines are divided into individual device chips by a laser processing apparatus. The device chips will be used in various electronic appliances including mobile phones, personal computers, and so on.

The laser processing apparatus includes a chuck table for holding a wafer as a workpiece thereon, a laser beam applying unit for applying a laser beam whose wavelength is transmittable through the wafer to the wafer held on the chuck table while positioning a focused

point of the laser beam within the wafer, thereby forming modified layers and cracks extending from the modified layers in the wafer, and a feed mechanism for processing-feeding the chuck table and the laser beam applying unit relatively to each other. When the laser processing apparatus is in operation, the laser beam is applied to the wafer while the focused point thereof is positioned in the wafer in alignment with one of projected dicing lines on the wafer, thereby forming modified layers as division initiating points at appropriate positions in the wafer. After modified layers have been formed in the wafer along all the projected dicing lines, external forces are applied to the wafer, dividing the wafer into individual device chips (see, for example, Japanese Patent No. 3408805).

According to the technology disclosed in Japanese Patent No. 3408805, providing the wafer has a small thickness ranging from approximately 50 to 150 μm , it is possible to position the focused point of the laser beam at appropriate positions in the wafer, to thereby form proper modified layers and cracks extending from the modified layers in the wafer. However, if the wafer has a large thickness in excess of 300 μm , for example, then problems arise in that the laser beam tends to suffer

from large aberrations due to the refractive index of the material of the wafer (e.g., the refractive index of silicon is generally 3.5), and fails to converge into a single focused point, with the result that the laser beam is unable to form proper modified layers in the wafer.

SUMMARY OF THE INVENTION

To cope with the above problems, it is conceivable that a spatial light phase modulator such as liquid crystal on silicon (LCOS) may be disposed between a laser oscillator and a beam condenser of the laser beam applying unit for correcting a spherical aberration in its entirety to allow the laser beam to converge into a single focused point. However, it is not easy to bring the center of a pattern for adjusting the spatial light phase modulator and the optical path of the laser beam into accurate alignment with each other. In the event that the center of the pattern for adjusting the spatial light phase modulator and the optical path of the laser beam deviate from each other, the laser beam fails to converge into a single focused point and has its processing power lowered, so that the laser processing apparatus cannot process wafers stably. The difficulty may be addressed by weakening the degree of the

correction of the spherical aberration by the spatial light phase modulator for the laser beam to assure a certain level of processing power even if the center of the pattern for adjusting the spatial light phase modulator and the optical path of the laser beam deviate somewhat from each other. However, the reduced degree of the correction of the spherical aberration tends to result in a reduction in the processing power of the laser beam.

It is therefore an object of the present invention to provide a laser processing apparatus that is capable of stabilizing and increasing the processing power of a laser beam even if the center of a pattern for adjusting a spatial light phase modulator and the optical path of the laser beam deviate somewhat from each other.

In accordance with an aspect of the present invention, there is provided a laser processing apparatus including a chuck table for holding a workpiece thereon, a laser beam applying unit for applying a laser beam having a wavelength transmittable through the workpiece held on the chuck table to the workpiece while positioning a focused point of the laser beam within the workpiece, thereby forming modified layers in the workpiece, and a feed mechanism for processing-feeding

the chuck table and the laser beam applying unit relatively to each other. The laser beam applying unit includes a laser oscillator for oscillating a laser and emitting the laser beam, a spatial light phase modulator for adjusting a phase of the laser beam emitted from the laser oscillator, a beam condenser for condensing the laser beam whose phase has been adjusted by the spatial light phase modulator and positioning a focused point of the laser beam within the workpiece, and a control unit for adjusting the spatial light phase modulator. The control unit has a storage section storing therein an adjustment pattern table for adjusting the spatial light phase modulator to produce in the workpiece a strongly corrected central area where relatively small aberrations occur and a weakly corrected outer peripheral area where relatively large aberrations occur at the focused point of the laser beam applied to and refracted by the workpiece.

Preferably, the strongly corrected central area takes up 20% to 30% of a total area of the laser beam emitted from the laser oscillator and is located centrally in the laser beam, and the weakly corrected outer peripheral area takes up a remainder of the total area of the laser beam around the strongly corrected

central area. Preferably, the adjustment pattern table includes a plurality of adjustment patterns according to which the spatial light phase modulator is to be adjusted depending on depths where the focused point of the laser beam is to be positioned within the workpiece, and selects one of the adjustment patterns according to the depth of a focused point indicated by an operator of the laser processing apparatus.

According to the present invention, even if the center of the adjustment pattern for adjusting the spatial light phase modulator and the optical path of the laser beam deviate from each other, the processing power of the laser beam is stabilized and increased.

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 a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view illustrating a manner in which a protective tape is laid on a wafer;

FIG. 2 is a perspective view of a laser processing apparatus according to an embodiment of the present invention;

FIG. 3 is a block diagram of an optical system of a laser beam applying unit of the laser processing apparatus illustrated in FIG. 2, together with an adjustment pattern table;

FIGS. 4A through 4C are plan views illustrating spots formed at a focused point;

FIG. 5 is an enlarged fragmentary cross-sectional view illustrating a laser processing step; and

FIG. 6 is a perspective view illustrating a manner in which a grinding step is carried out.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A laser processing apparatus according to a preferred embodiment of the present invention will hereinafter be described with reference to the accompanying drawings. FIG. 1 illustrates in perspective a wafer 10 prepared as a workpiece to be processed by the laser processing apparatus according to the present embodiment and a protective tape T, and also illustrates a manner in which the protective tape T is laid on a face side 10a of the wafer 10. The wafer 10 includes, for

example, a silicon wafer having a thickness of 700 μm . The wafer 10 has a plurality of devices 12 formed on the face side 10a in respective areas thereof demarcated by a plurality of intersecting projected dicing lines 14 established on the face side 10a. The protective tape T includes a tape of resin including an adhesive layer and is integrally combined with the wafer 10 by being affixed to the face side 10a of the wafer 10.

FIG. 2 illustrates in perspective a laser processing apparatus 2 according to the present embodiment. As illustrated in FIG. 2, the laser processing apparatus 2 includes a base 3, a holding unit 4 for holding a workpiece thereon, a laser beam applying unit 6, an image capturing unit 7, a moving mechanism 30 for moving the holding unit 4, provided as a feed mechanism for processing-feeding the holding unit 4 and the laser beam applying unit 6 relatively to each other, and a control unit to be described later.

The holding unit 4 includes a rectangular X-axis movable plate 21 movably disposed on the base 3 for movement in X-axis directions indicated by an arrow X, a rectangular Y-axis movable plate 22 movably disposed on the X-axis movable plate 21 for movement in Y-axis directions indicated by an arrow Y that are perpendicular

to the X-axis directions, a hollow cylindrical post 23 fixedly mounted on an upper surface of the Y-axis movable plate 22, and a rectangular cover plate 26 fixed to an upper end of the post 23. The cover plate 26 has an oblong hole that is defined therein and that houses a circular chuck table 25 extending upwardly therethrough. The chuck table 25 is rotatable about its vertical central axis by a rotating mechanism, not illustrated. The chuck table 25 has an upper surface acting as a holding surface 25a whose horizontal positions are defined by X-axis coordinates and Y-axis coordinates. The holding surface 25a is made of a porous material and hence is air-permeable, and is connected to suction means, not illustrated, through a fluid channel defined in the post 23.

The moving mechanism 30 which is disposed on the base 3 includes an X-axis feed mechanism 31 for processing-feeding the holding unit 4 in the X-axis directions and a Y-axis feed mechanism 32 for indexing-feeding the Y-axis movable plate 22 in the Y-axis directions. The X-axis feed mechanism 31 converts rotary motion of a stepping motor 33 into linear motion through a ball screw 34 and transmits the linear motion to the X-axis movable plate 21, moving the X-axis movable plate 21

in one of the X-axis directions or the other along a pair of guide rails 3a mounted on the base 3. The Y-axis feed mechanism 32 converts rotary motion of a stepping motor 35 into linear motion through a ball screw 36 and transmits the linear motion to the Y-axis movable plate 22, moving the Y-axis movable plate 22 in one of the Y-axis directions or the other along a pair of guide rails 21a mounted on the X-axis movable plate 21. Incidentally, although not illustrated, position detecting means is disposed on each of the X-axis feed mechanism 31, the Y-axis feed mechanism 32, and the chuck table 25 for accurately detecting X-axis and Y-axis coordinates and circumferentially angular position of the chuck table 25 and sending the detected coordinates and angular position as positional information of the chuck table 25 to the control unit of the laser processing apparatus 2. The control unit issues command signals based on the received positional information to actuate the X-axis feed mechanism 31, the Y-axis feed mechanism 32, and the rotating mechanism, not illustrated, of the chuck table 25 to thereby position the chuck table 25 at a desired position on the base 3 and turning the chuck table 25 to a desired circumferentially angular position.

As illustrated in FIG. 2, the laser processing

apparatus 2 further includes a frame 37 erected on the base 3 sideways of the moving mechanism 30. The frame 37 includes a vertical wall 37a disposed on the base 3 and extending vertically along Z-axis directions perpendicular to the X-axis directions and the Y-axis directions and a horizontal wall 37b extending horizontally from an upper end portion of the vertical wall 37a in overhanging relation to the moving mechanism 30. The horizontal wall 37b houses therein an optical system of the laser beam applying unit 6. The optical system includes a beam condenser 67, to be described later, disposed on the lower surface of a distal end portion of the horizontal wall 37b.

The image capturing unit 7 is disposed on the lower surface of the distal end portion of the horizontal wall 37b at a position spaced from the beam condenser 67 along the X-axis directions. The image capturing unit 7 includes an ordinary image capturing element, e.g., a charge coupled device (CCD), for capturing images with a visible light beam, an infrared radiation source for emitting infrared rays toward the chuck table 25, and an image capturing element, e.g., an infrared CCD, for detecting infrared rays emitted by the infrared radiation source and reflected from the chuck table 25 and

outputting an electric signal representing the detected infrared rays. Images captured by the image capturing unit 7 are sent to the control unit, which displays the images on a suitable display unit that is not illustrated.

The optical system of the laser beam applying unit 6 housed in the horizontal wall 37b of the laser processing apparatus 2 will be described below with reference to FIG. 3. As illustrated in FIG. 3, the laser beam applying unit 6 includes a laser oscillator 61 for oscillating a laser and emitting a laser beam LB0, i.e., a pulsed laser beam according to the present embodiment, having a wavelength transmittable through the wafer 10 held on the chuck table 25, an attenuator 62 for adjusting the output level of the laser beam LB0 emitted from the laser oscillator 61 to a desired output level, a spatial light phase modulator 63 such as LCOS for adjusting the phase of the laser beam LB0 whose output level has been adjusted by the attenuator 62 and outputting a phase-adjusted laser beam LB1, a beam condenser 67 having a condensing lens 67a for converging the laser beam LB1 adjusted in phase by the spatial light phase modulator 63 and positioning a focused point of the laser beam LB1 in the wafer 10 on the chuck table 25, and

a control unit 100 for adjusting the spatial light phase modulator 63. Note that the condensing lens 67a may include a single lens or a compound lens made up of a plurality of lenses.

The control unit 100 includes a computer and is electrically connected to input means 8 for entering control instructions from an operator when necessary. The control unit 100 adjusts operation of the spatial light phase modulator 63. Further, the control unit 100 has a memory including a storage section 110 where an adjustment pattern table 112 illustrated in FIG. 3 is stored. The adjustment pattern table 112 includes a plurality of adjustment patterns 114 according to which the spatial light phase modulator 63 is to be adjusted depending on depths D where the focused point of the laser beam LB1 is to be positioned within the wafer 10. Incidentally, the laser beam applying unit 6, the image capturing unit 7, the moving mechanism 30, etc., of the laser processing apparatus 2 are also electrically connected to the control unit 100 according to the present embodiment, and will be controlled by the control unit 100. However, the spatial light phase modulator 63 may be adjusted by another separate dedicated control unit.

The spatial light phase modulator 63 has a liquid crystal disposed on a substrate of silicon. The liquid crystal includes a plurality of pixels, e.g., aluminum electrodes, disposed in an uppermost layer. The potentials of the respective pixels are independently controlled according to one of the adjustment patterns 114 that is selected by the adjustment pattern table 112 illustrated in FIG. 3 to modulate the wavefront of the laser beam LB0 as it passes through the liquid crystal, i.e., to modulate a spatial phase distribution.

Functions and operation of the spatial light phase modulator 63 according to the present embodiment will be described below with reference to FIGS. 4A through 4C as well as FIG. 3. As described above with respect to the related art, if the wafer 10 has a large thickness, then the laser beam tends to suffer from large aberrations at the focused point positioned in the wafer 10 due to the refractive index of the material of the wafer 10, which is generally 3.5 as the wafer 10 is made of silicon in the present embodiment, and fails to converge into a single focused point, with the result that the laser beam is unable to form proper modified layers in the wafer. According to the present embodiment, the above difficulty is addressed by referring to the adjustment pattern table

112 stored in the storage section 110 of the control unit 100, selecting one of the adjustment patterns 114 that corresponds to a desired depth D where the focused point of the laser beam LB1 is to be formed in the wafer 10, and adjusting the spatial light phase modulator 63 on the basis of the selected adjustment pattern 114. For example, in a case where the desired depth D where the focused point of the laser beam LB1 is to be formed in the wafer 10 is 300 μm , an adjustment pattern 114a is selected by referring to the adjustment pattern table 112, and the spatial light phase modulator 63 is controlled according to the selected adjustment pattern 114a. FIG. 4A illustrates a laser beam spot S1 formed at a focused point P by the laser beam LB1 in the wafer 10 at this time.

When the adjustment pattern 114a is selected by referring to the adjustment pattern table 112 and the spatial light phase modulator 63 is adjusted according to the selected adjustment pattern 114a, the laser beam spot S1 formed at the focused point P in the wafer 10 by the laser beam LB1 includes, as illustrated in FIG. 4A, a strongly corrected central area S1a indicated by the dotted line where relatively small aberrations occur and a weakly corrected outer peripheral area S1b where

aberrations larger than those in the central area S1a occur around the central area S1a in concentric relation thereto. Note that laser beam spots including central and outer peripheral areas according to the present invention are not limited to the concentric laser beam spot S1 illustrated in FIG. 4A, and may include a square laser beam spot S2 illustrated in FIG. 4B and a triangular laser beam spot S3 illustrated in FIG. 4C, for example. The square laser beam spot S2 illustrated in FIG. 4B that is formed at the focused point P in the wafer 10 by the laser beam LB1 includes, as illustrated in FIG. 4B, a strongly corrected central area S2a formed centrally in the laser beam spot S2 and a weakly corrected outer peripheral area S2b formed around the central area S1a. Similarly, the triangular laser beam spot S3 illustrated in FIG. 4C that is formed at the focused point P in the wafer 10 by the laser beam LB1 includes, as illustrated in FIG. 4C, a strongly corrected central area S3a formed centrally in the laser beam spot S3 and a weakly corrected outer peripheral area S3b formed around the central area S3a.

The inventors of the present invention have conducted experiments and simulations to find out about appropriate ratios of the areas of strongly corrected

central areas where relatively small aberrations occur and weakly corrected outer peripheral areas where aberrations larger than those in the central area occur around the central areas in concentric relation thereto. As a result of the experiments and simulations, the inventors have found that, by setting the area of a strongly corrected central area where relatively small aberrations occur to 20% to 30% of the total area of the laser beam spot, the processing power of the laser beam LB1 is stabilized to perform a laser processing process without compromising the processing power even if the center of the adjustment pattern 114 for adjusting the spatial light phase modulator 63 and the optical axis of the laser beam LB0 deviate from each other.

Note that the degree of strength of correction with respect to the central area S1a and the outer peripheral area S1b of the laser beam spot S1 illustrated in FIG. 4A is established on the basis of the following technical idea.

There is known in the art the fringe Zernike polynomial (hereinafter referred to as "Zernike polynomial") as a polynomial for approximating the wavefront aberration of an image capturing optical system. The Zernike polynomial is generally known as a

polynomial expressed using a polar coordinate (r, θ) where r represents the radius of a unit circle and θ represents a rotational angle. A ninth term ([Z9]) of the Zernike polynomial is indicated by the equation,

$$[Z9] = 6r^4 - 6r^2 + 1 \quad \cdots (1)$$

which represents a spherical aberration. The central area S1a that is strongly corrected by the spatial light phase modulator 63 serves to correct the aberration at the position of the focal point at the desired depth D with the strong correction so as to make the aberration as close to zero as possible. On the other hand, the outer peripheral area S1b that is weakly corrected by the spatial light phase modulator 63 is calculated to make the values of the coefficients of the ninth term of the Zernike polynomial larger than those according to the strong correction by approximately 0.05 to 0.09, or preferably by approximately 0.07.

The laser processing apparatus 2 according to the present embodiment is generally arranged as described above. Operation and advantages of the laser processing apparatus 2 will be described below. For processing the wafer 10 with a laser beam using the laser processing apparatus 2 illustrated in FIG. 2, the wafer 10 described with reference to FIG. 1 is unloaded from a cassette, not

illustrated, and placed on the holding surface 25a of the chuck table 25 with the reverse side 10b of the wafer 10 facing upwardly and the protective tape T facing downwardly. Then, the suction means, not illustrated, is actuated to hold the wafer 10 under suction on the holding surface 25a.

Then, the moving mechanism 30 is actuated to position the wafer 10 below the image capturing unit 7, and then stopped. The image capturing unit 7 applies infrared rays to the wafer 10 from the reverse side 10b thereof to capture an image of the wafer 10. The position of one of the projected dicing lines 14 on the face side 10a along which the wafer 10 is to be divided is detected from the image and stored in the control unit 100 (alignment step).

After the alignment step, the moving mechanism 30 is actuated again to move the wafer 10 below the beam condenser 67 and also to bring the projected dicing line 14 into alignment with a direction along processing feed directions, i.e., the X-axis directions, and position a location where the wafer 10 is to start to be processed on the projected dicing line 14 directly below the beam condenser 67.

Next, the laser beam applying unit 6 is energized

to generate a laser beam LB1 whose wavelength is transmittable through the material, i.e., silicon, of the wafer 10 so as to position the focused point P of the laser beam LB1 within the wafer F at a desired depth D (see FIG. 5) therein. As illustrated in FIG. 5, the laser beam LB1 is applied to the wafer 10 from the reverse side 10b thereof at a region of the wafer 10 where the wafer 10 is to be divided, i.e., the projected dicing line 14, while at the same time the moving mechanism 30 is actuated to processing-feed the chuck table 25 in one of the X-axis directions indicated by the arrow X, thereby forming modified layers 18 in the wafer 10 along the projected dicing line 14.

As illustrated in FIG. 5, the modified layers 18 include a first modified layer 18a, a second modified layer 18b, and a third modified layer 18c situated respectively at different depths. The first modified layer 18a has a depth D of 550 μm , for example. For energizing the laser beam applying unit 6 in order to form the first modified layer 18a, an adjustment pattern 114b is selected by referring to the adjustment pattern table 112 stored in the storage section 110 of the control unit 100 illustrated in FIG. 3, and the spatial light phase modulator 63 is adjusted according to the

selected adjustment pattern 114b. The adjusted spatial light phase modulator 63 applies the laser beam LB1 to the wafer 10. Further, the second modified layer 18b has a depth D of 500 μm , for example. For energizing the laser beam applying unit 6 in order to form the second modified layer 18b, an adjustment pattern 114c is selected by referring to the adjustment pattern table 112 stored in the storage section 110 of the control unit 100, and the spatial light phase modulator 63 is adjusted according to the selected adjustment pattern 114c. The adjusted spatial light phase modulator 63 applies the laser beam LB1 to the wafer 10. In addition, the third modified layer 18c has a depth D of 450 μm , for example. For energizing the laser beam applying unit 6 in order to form the third modified layer 18c, an adjustment pattern 114d is selected by referring to the adjustment pattern table 112 stored in the storage section 110 of the control unit 100, and the spatial light phase modulator 63 is adjusted according to the selected adjustment pattern 114d. The adjusted spatial light phase modulator 63 applies the laser beam LB1 to the wafer 10.

For forming the first through third modified layers 18a through 18c having the respective different depths D, as described above, the spatial light phase modulator 63

is adjusted in a manner to match the desired depths D where the focused point P is formed, and the laser beam LB1 is applied from the adjusted spatial light phase modulator 63 to the wafer 10 to produce in the wafer 10 the laser beam spot S1 including the strongly corrected central area S1a where relatively small aberrations occur and the weakly corrected outer peripheral area S1b where relatively large aberrations occur around the central area S1a at the focused point P of the laser beam LB1 applied to and refracted by the wafer 10, thereby forming the first through third modified layers 18a through 18c in the wafer 10. As the chuck table 25 is processing-fed in the X-axis direction, the first through third modified layers 18a through 18c are successively formed in the wafer 10 while at the same time cracks 19 are also formed therein to interconnect the first through third modified layers 18a through 18c and reach the face side 10a of the wafer 10.

After the modified layers 18 and the cracks 19 have been formed in the wafer 10 along the projected dicing line 14 that extends in a predetermined first direction, the moving mechanism 30 is actuated to move the wafer 10 by an interval equal to the distance between two projected dicing lines 14 in one of the Y-axis

directions, which is normal to the sheet of FIG. 5, perpendicular to the X-axis directions, positioning an adjacent projected dicing line 14 in the Y-axis direction that extends in the first direction directly below the beam condenser 67. Then, the laser beam LB1 is applied to the wafer 10 on the positioned projected dicing line 14 and at the same time the chuck table 25 is processing-fed in one of the X-axis directions, thereby forming modified layers 18 and cracks 19 in the wafer 10 along the projected dicing line 14, in the same manner as described above.

The above processing sequence is repeated to apply the laser beam LB1 to the wafer 10 along all the projected dicing lines 14 extending in the first direction to form modified layers 18 and cracks 19 in the wafer 10 along those projected dicing lines 14. Then, the wafer 10 is turned 90 degrees about its central axis by the chuck table 25 to bring one of the projected dicing lines 14 extending along a predetermined second direction perpendicular to the first direction into alignment with the X-axis directions. The laser beam LB1 is applied to the wafer 10 along the projected dicing line 14 with the focused point P at the desired depth D, forming modified layers 18 and cracks 19 in the wafer 10. Similarly, the

laser beam LB1 is applied to the wafer 10 along all the projected dicing line 14 extending in the second directions, forming modified layers 18 and cracks 19 in the wafer 10 along all the projected dicing line 14 extending in the second directions (laser processing step).

Note that the above laser processing step is carried out by the laser processing apparatus 2 under the following processing conditions, for example.

Wavelength: 1099 nm

Average output power: 2.6 W

Repetitive frequency: 120 kHz

Feed speed: 800 mm/second

The wafer 10 processed with the laser beam LB1 by the laser processing apparatus 2 is delivered to a grinding apparatus 50, partly illustrated in FIG. 6. The grinding apparatus 50 performs a grinding process on the wafer 10 as follows.

As illustrated in FIG. 6, the grinding apparatus 50 includes a chuck table 51 and a grinding unit 52. The chuck table 51 has an upper holding surface provided by a porous surface connected to a suction source, not illustrated. When the suction source is actuated, it generates and applies a negative pressure to the upper

holding surface to hold the wafer 10 under suction thereon. The chuck table 51 includes rotating means and moving means, both not illustrated. When the rotating means is actuated, it rotates the chuck table 51 about a vertical central axis thereof. When the moving means is actuated, it moves the chuck table 51 between a loading and unloading area where the wafer 10 can be loaded onto and unloaded from the chuck table 51 and a grinding area where the wafer 10 on the chuck table 51 can be ground by the grinding unit 52. The grinding unit 52 includes a spindle 53 rotatable about a vertical central axis thereof by an electric motor, not illustrated, a wheel mount 54 fixedly mounted on a lower end of the spindle 53, a grinding wheel 55 fixedly mounted on a lower surface of the wheel mount 54, and a plurality of grindstones 56 disposed in an annular array on a lower surface of the grinding wheel 55.

The wafer 10 delivered to the grinding apparatus 50 is placed on the holding surface of the chuck table 51 positioned in the loading and unloading area with the reverse side 10b of the wafer 10 facing upwardly and the protective tape T facing downwardly, as illustrated in FIG. 6. Then, the suction means, not illustrated, is actuated to hold the wafer 10 under suction on the

holding surface of the chuck table 51. Then, the chuck table 51 is moved by the moving means to a position directly below the grinding unit 52, i.e., the grinding area, where the center of the wafer 10 held on the chuck table 51 is aligned, as viewed from above, with a position through which the annular array of the grindstones 56 will move to grind the wafer 10.

After the wafer 10 has been positioned in the grinding area, the chuck table 51 is rotated in the direction indicated by an arrow R1 at a speed of 300 rpm, for example, while at the same time the spindle 53 of the grinding unit 52 is rotated in the direction indicated by an arrow R2 at a speed of 6000 rpm, for example. Then, a grinding feed unit, not illustrated, is actuated to lower the grinding unit 52 in the direction indicated by an arrow R3 toward the chuck table 51. The grindstones 56 are now brought into contact with the reverse side 10b of the wafer 10, and are grinding-fed downwardly at a grinding feed speed of 1.0 $\mu\text{m}/\text{second}$, for example, by the grinding feed unit, thereby grinding the reverse side 10b of the wafer 01. At this time, a measurement gage, not illustrated, should preferably measure the thickness of the wafer 10 as the wafer 10 is ground. The grinding process thus performed thins down the wafer 10 and

fractures the wafer 10 along the projected dicing lines 14, dividing the wafer 10 into individual device chips 12', as illustrated in FIG. 6. After the grinding process, the wafer 10 is delivered to a next process or stored into a cassette, not illustrated.

According to the present embodiment, even if the center of the adjustment pattern for adjusting the spatial light phase modulator 63 and the optical path of the laser beam LB0 deviate from each other, the processing power of the laser beam LB1 is stabilized and increased. Note that the adjustment pattern table 112 described above is illustrated by way of example only and should not be construed as being limited to the details illustrated in FIG. 3.

The present invention is not limited to the details of the above described preferred embodiment. 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 apparatus comprising:
 - a chuck table for holding a workpiece thereon;
 - a laser beam applying unit for applying a laser beam having a wavelength transmittable through the workpiece held on the chuck table to the workpiece while positioning a focused point of the laser beam within the workpiece, thereby forming modified layers in the workpiece; and
 - a feed mechanism for processing-feeding the chuck table and the laser beam applying unit relatively to each other, wherein
 - the laser beam applying unit includes
 - a laser oscillator for oscillating a laser and emitting the laser beam,
 - a spatial light phase modulator for adjusting a phase of the laser beam emitted from the laser oscillator,
 - a beam condenser for condensing the laser beam whose phase has been adjusted by the spatial light phase modulator and positioning a focused point of the laser beam within the workpiece, and
 - a control unit for adjusting the spatial light phase modulator, and

the control unit has a storage section storing therein an adjustment pattern table for adjusting the spatial light phase modulator to produce in the workpiece a strongly corrected central area where relatively small aberrations occur and a weakly corrected outer peripheral area where relatively large aberrations occur at the focused point of the laser beam applied to and refracted by the workpiece,

wherein the strongly corrected central area takes up 20% to 30% of a total area of the laser beam emitted from the laser oscillator and is located centrally in the laser beam; and

the weakly corrected outer peripheral area takes up a remainder of the total area of the laser beam around the strongly corrected central area.

2. The laser processing apparatus according to claim 1, wherein

the adjustment pattern table includes a plurality of adjustment patterns according to which the spatial light phase modulator is to be adjusted depending on depths where the focused point of the laser beam is to be positioned within the workpiece, and selects one of the adjustment patterns according to a depth of a focused point indicated by an operator of the laser processing

apparatus.

3. The laser processing apparatus according to claim 1, wherein

the spatial light phase modulator is adjusted by a separate dedicated control unit.

4. The laser processing apparatus according to claim 1, wherein

a degree of strength of correction with respect to the strongly corrected central area and the weakly corrected outer peripheral area is established on a basis of a fringe Zernike polynomial, expressed using a polar coordinate (r, θ) , where r represents a radius of a unit circle and θ represents a rotational angle; and

a ninth term of the fringe Zernike polynomial, represented by $[Z9]$, is indicated by an equation

$$[Z9] = 6r^4 - 6r^2 + 1,$$

which represents a spherical aberration.

5. The laser processing apparatus according to claim 4, wherein

the strongly corrected central area that is strongly corrected by the spatial light phase modulator serves to correct an aberration at the depth where the focused point of the laser beam is to be positioned within the workpiece with a strong correction so as to

make the aberration as close to zero as possible; and

the weakly corrected outer peripheral area that is weakly corrected by the spatial light phase modulator is calculated to make values of coefficients of the ninth term of the fringe Zernike polynomial larger than those according to the strong correction by approximately 0.05 to 0.09, or preferably by approximately 0.07.