

Title of the Invention

Processing Apparatus Using Laser Beam

Field of the Invention

5 This invention relates to a processing apparatus using a laser beam and, more particularly, a processing apparatus comprising holding means for holding a workpiece, and laser beam application means for irradiating the workpiece, which is held by the holding means, with a
10 pulsed laser beam capable of passing through the workpiece, thereby deteriorating the workpiece.

Description of the Prior Art

 In the production of a semiconductor device, for
15 example, it is well known that many semiconductor circuits are formed on the face of a wafer, including a suitable substrate, such as a silicon substrate, a sapphire substrate, a silicon carbide substrate, a lithium tantalate substrate, a glass substrate, or a quartz
20 substrate, and then the wafer is divided to produce individual semiconductor circuits, namely, semiconductor devices. Various modes using a laser beam are proposed as methods for dividing the wafer.

 U.S. Patent 6,211,488 and Japanese Patent
25 Application Laid-Open No. 2001-277163 each disclose a wafer dividing method which focuses a pulsed laser beam onto an intermediate portion in the thickness direction of a wafer, moves the pulsed laser beam and the wafer relative to each other along a division line to generate a
30 deterioration region along the division line in the intermediate portion in the thickness direction of the wafer, and then exerts an external force on the wafer to break the wafer along the deterioration region.

 It is conceivable not only to generate the
35 deterioration region in the intermediate portion in the

thickness direction of the wafer, but also to form a deterioration region along the division line in a portion ranging from the back of the wafer to a predetermined depth, or in a portion ranging from the face of the wafer to a predetermined depth, instead of or in addition to the intermediate portion in the thickness direction of the wafer. In each case, in order to exert an external force on the wafer to break the wafer along the division line sufficiently precisely, it is necessary to provide a relatively large thickness of the deterioration region, namely, a relatively large dimension of the deterioration region in the thickness direction of the wafer. To increase the thickness of the deterioration region, there is need to displace the position of the focus point of the pulsed laser beam in the thickness direction of the wafer, and repeatedly move the pulsed laser beam and the wafer relative to each other along the division line, because the deterioration region is generated in the vicinity of the focus point of the pulsed laser beam. If the thickness of the wafer is relatively large, therefore, it takes a relatively long time to generate the deterioration region of a necessary thickness to break the wafer sufficiently precisely.

In an attempt to solve the above-described problems, the specification and drawings of Japanese Patent Application No. 2003-273341, filed by the applicant (the assignee) of the present application, disclose a processing apparatus adapted to focus a pulsed laser beam to at least two focus points displaced in the direction of the optical axis. According to such a processing apparatus, deterioration regions can be simultaneously generated on at least two sites displaced in the thickness direction of a workpiece, namely, a wafer. However, the processing apparatus is still not sufficiently satisfactory, but poses the following problems to be

solved: Deterioration at one of the two focus points, more specifically, the focus point at a shorter distance from pulsed laser beam oscillation means, inhibits application of the pulsed laser beam to the other focus point, more specifically, the focus point at a longer distance from the pulsed laser beam oscillation means, thereby inhibiting the generation of desired deterioration.

Summary of the Invention

10 It is a principal object of the present invention, therefore, to provide a novel and improved processing apparatus using a laser beam, the processing apparatus being capable of generating deterioration, as desired, on at least two focus points displaced in the thickness direction of a workpiece, while ingeniously avoiding a situation where deterioration of one of the two focus points inhibits application of a pulsed laser beam to the other focus point, thereby generating a deterioration region of a required thickness in the workpiece.

20 We, the inventors, diligently conducted studies and experiments, and have found the following facts: A pulsed laser beam is focused, with some time difference provided, to at least two focus points displaced in the optical axis direction of the pulsed laser beam, accordingly, displaced in the thickness direction of a workpiece. As a result, a situation where deterioration at one of the focus points inhibits application of the pulsed laser beam to the other focus point can be avoided. Thus, the aforementioned principal object can be attained.

30 That is, according to the present invention, as a processing apparatus using a laser beam for attaining the above-mentioned principal object, there is provided a processing apparatus using a laser beam, which comprises holding means for holding a workpiece, and laser beam application means for irradiating the workpiece, held by

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the holding means, with a pulsed laser beam capable of passing through the workpiece, thereby deteriorating the workpiece, the laser beam application means including pulsed laser beam oscillation means and
5 transmitting/focusing means for transmitting and focusing the pulsed laser beam oscillated by the pulsed laser beam oscillation means, wherein the transmitting/focusing means focuses the pulsed laser beam, with a time difference provided, to at least two focus points displaced in the
10 optical axis direction of the pulsed laser beam.

Preferably, the transmitting/focusing means focuses the laser beam to the focus point at a longer distance from the pulsed laser beam oscillation means earlier than the focus point at a shorter distance from the pulsed
15 laser beam oscillation means. The time difference during focusing between the focus points adjacent in the optical axis direction is preferably not smaller than one pulse duration of the pulsed laser beam, but not larger than a time interval between successive pulses of the pulsed
20 laser beam. In a preferred embodiment, the transmitting/focusing means includes a splitter for dividing the pulsed laser beam from the pulsed laser beam oscillation means into a first pulsed laser beam and a second pulsed laser beam; a plurality of mirrors for
25 aligning the optical axis of the second pulsed laser beam with the optical axis of the first pulsed laser beam; diameter changing means for changing the diameter of one of the first pulsed laser beam and the second pulsed laser beam; and a common focusing lens. Preferably, the
30 transmitting/focusing means includes optical path length increasing means for increasing the optical path length of one of the first pulsed laser beam and the second pulsed laser beam. The optical path length increasing means preferably includes an optical fiber or a plurality of
35 mirrors.

In the processing apparatus using a laser beam according to the present invention, a time difference is caused to exist in the focusing of the pulsed laser beam at each of at least two focus points. Hence, a situation where deterioration generated at one of the focus points inhibits application of the pulsed laser beam to the other focus point is avoided. Consequently, deterioration, as desired, can be generated on at least two focus points.

10 Brief Description of the Drawings

FIG. 1 is a schematic view showing a preferred embodiment of a processing apparatus constructed in accordance with the present invention.

FIG. 2 is a graph showing a time difference during focusing between a first pulsed laser beam and a second pulsed laser beam in the processing apparatus of FIG. 1.

FIG. 3 is a schematic view showing another embodiment of a processing apparatus constructed in accordance with the present invention.

FIG. 4 is a graph showing a time difference during focusing among a first pulsed laser beam, a second pulsed laser beam, and a third pulsed laser beam in the processing apparatus of FIG. 3.

25 Detailed Description of the Preferred Embodiments

Preferred embodiments of a processing apparatus using a laser beam, which is constructed in accordance with the present invention, will now be described in greater detail by reference to the accompanying drawings.

FIG. 1 schematically shows a preferred embodiment of a processing apparatus constructed in accordance with the present invention. The illustrated processing apparatus comprises holding means 4 for holding a workpiece 2, and laser beam application means indicated entirely at the numeral 6.

The holding means 4 is composed of a holding member 8 formed, for example, from a porous member or having a plurality of suction holes or grooves formed therein, and suction means (not shown) annexed to the holding member 8. 5 The holding means 4 may be of a form in which the workpiece 2, for example, a wafer, is attracted to the surface of the holding member 8 by suction.

The laser beam application means 6 includes pulsed laser beam oscillation means 10, and transmitting/focusing means 12 for transmitting and focusing a pulsed laser beam oscillated by the pulsed laser beam oscillation means 10. 10 Importantly, the pulsed laser beam oscillation means 10 oscillates a pulsed laser beam 14 which can pass through the workpiece 2. If the workpiece 2 is a wafer including 15 a silicon substrate, a sapphire substrate, a silicon carbide substrate, a lithium tantalate substrate, a glass substrate, or a quartz substrate, the pulsed laser beam oscillation means 10 can be advantageously formed from a YVO4 pulsed laser oscillator or a YAG pulsed laser 20 oscillator which oscillates the pulsed laser beam 14 having a wavelength of, for example, 1064 nm.

With reference to FIG. 1, the transmitting/focusing means 12 in the laser beam application means 6 is interposed between the pulsed laser beam oscillation means 25 10 and the workpiece 2 held on the holding means 4. The transmitting/focusing means 12 in the illustrated embodiment includes a half mirror 16 functioning as a splitter, a mirror 18, a mirror 20, a half mirror 22, diameter changing means 24 disposed between the half 30 mirror 16 and the half mirror 22, and optical path length increasing means 26 disposed between the mirror 18 and the mirror 20. The diameter changing means 24 is composed of an expander having two convex lenses 28 and 30. The optical path length increasing means 26 for increasing the 35 optical path between the mirror 18 and the mirror 20 by,

for example, several meters can be composed of an optical fiber extending, for example, over several meters. Alternatively, the optical path length increasing means 26 can be composed of a plurality of mirrors instead of, or
5 in addition to, the optical fiber. The transmitting/focusing means 12 further includes a focusing lens 32 for focusing the pulsed laser beam 14.

In the above-described processing apparatus, the pulsed laser beam 14 oscillated from the pulsed laser beam
10 oscillation means 10 is separated by the half mirror 16 into two pulsed laser beams 14a and 14b, namely, the first pulsed laser beam 14a which passes through the half mirror 16 and advances straightly, and the second pulsed laser beam 14b which is reflected by the half mirror 16 and
15 changed in direction to a substantially perpendicular direction. The first pulsed laser beam 14a passes through the diameter changing means 24, and thereby has its diameter changed, more specifically, is converted into a form in which its diameter gradually increases as the
20 first pulsed laser beam 14a goes farther from the diameter changing means 24. Then, the first pulsed laser beam 14a passes through the half mirror 22, and is focused by the focusing lens 32 to a focus point 34a in the workpiece 2. On the other hand, the second pulsed laser beam 14b is
25 reflected by the mirror 18, the mirror 20, and the half mirror 22 to be changed in direction to a substantially perpendicular direction at each time, and is finally brought into a state where its optical axis aligns with the optical axis of the first pulsed laser beam 14a. Then,
30 the second pulsed laser beam 14b is focused by the focusing lens 32 to a focus point 34b in the workpiece 2. As clearly shown in FIG. 1, the focus point 34a and the focus point 34b are displaced in the optical axis direction of the first and second pulsed laser beams 14a
35 and 14b, and the focus point 34a is located more remotely

from the pulsed laser beam oscillation means 10 than the focus point 34b. The position of the focus point 34a can be adjusted, as appropriate, by moving the expander, which constitutes the diameter changing means 24, in the optical axis direction, or by moving the convex lens 28 or 30 of the expander in the optical axis direction.

In the illustrated embodiment, the optical path of the second pulsed laser beam 14b extends to the half mirror 22 via the half mirror 16, the mirror 18, the optical path length increasing means 26, and the mirror 20, so that the optical path length of the second pulsed laser beam 14b is increased by, for example, several meters as compared with the optical path length of the first pulsed laser beam 14a. Thus, the second pulsed laser beam 14b arrives at the focus point 34b later than a point in time, when the first pulsed laser beam 14a reaches the focus point 34a, by a time required for the second pulsed laser beam 14b to pass over the increased optical path length. As shown in FIG. 2, it is preferred that a time difference dt between the point in time, when the first pulsed laser beam 14a arrives at the focus point 34a, and a point in time, when the second pulsed laser beam 14b arrives at the focus point 34b, is not smaller than one pulse duration (pulse width) Δt of the pulsed laser beam 14a (or 14b), but not larger than a time interval gt between successive pulses of the pulsed laser beam 14a (or 14b), and that each pulse of the second pulsed laser beam 14b is located between respective pulses of the first pulsed laser beam 14a. For example, let each pulse duration of the pulsed laser beams 14a and 14b be Δt (seconds), and the repetition frequency of the pulsed laser beams 14a and 14b be W (Hz), and the difference between the optical path length ($L1$) of the first pulsed laser beam 14a and the optical path length ($L2$) of the second pulsed laser beam 14b be DL . Since the velocity of light is c ($=3 \times 10^8$

m/second), the above time difference dt is $(L2-L1)/c$. Thus, the second optical path length $L2$ may be increased so as to satisfy $\Delta t \times c \leq (L2-L1) \leq (1/W-\Delta t) \times c$. For example, if the pulse duration Δt is 10 ns, and the pulse
5 repetition frequency W is 100 k (Hz), then it is recommendable to increase the optical path length $L2$ of the second pulsed laser beam 14b by about 3 m as compared with the optical path length $L1$ of the first pulsed laser beam 14a.

10 When the first pulsed laser beam 14a is focused to the focus point 34a, deterioration is generated in the workpiece 2, because of this focusing, in the vicinity of the focus point 34a, usually, in a region having some width $W1$ from the focus point 34a upward. When the second
15 pulsed laser beam 14b is focused to the focus point 34b, deterioration is generated in the workpiece 2 in the vicinity of the focus point 34b, usually, in a region having some width $W2$ from the focus point 34b upward. If the arrival of the first pulsed laser beam 14a at the
20 focus point 34a, and the arrival of the second pulsed laser beam 14b at the focus point 34b are substantially simultaneous, there is a tendency that the first pulsed laser beam 14a focused to the focus point 34a is adversely affected by the deterioration generated at the focus point
25 34b, and the generation of desired deterioration in the vicinity of the focus point 34a is inhibited. Assume, by contrast, that the first pulsed laser beam 14a is focused to the focus point 34a to start the generation of deterioration in the vicinity of the focus point 34a, and
30 then, with a time difference provided, the second pulsed laser beam 14b is focused to the focus point 34b to start the generation of deterioration in the vicinity of the focus point 34b. In this case, the situation where the focusing of the first pulsed laser beam 14a to the focus
35 point 34a is inhibited by the generation of deterioration

by the second pulsed laser beam 14b in the vicinity of the focus point 34b is fully avoided, and desired deterioration can be generated in the vicinity of the focus point 34a and in the vicinity of the focus point 34b.

5 The above-mentioned deterioration in the workpiece 2 occurs as melting and resolidification (namely, melting when the laser beams 14a and 14b are focused, and solidification after the focusing of the pulsed laser beams 14a and 14b is completed), and appears as voids or
10 cracks, although this is dependent on the material for the workpiece 2, or the intensity of the pulsed laser beams 14a and 14b focused. When the laser beam application means 6 and the holding means 4 are relatively moved along the division line extending, for example, in the right-
15 and-left direction in FIG. 1, two deterioration portions continuously extending along the division line with a width W1 and a width W2 (if the spots of the laser beams 14a and 14b at the focus points 34a and 34b, the spots being adjacent in the relative movement direction, overlap
20 partially), or many deterioration portions located with spacing along the division line with the width W1 and the width W2 (if the spots of the laser beams 14a and 14b at the focus points 34a and 34b, the spots being adjacent in the relative movement direction, are located with spacing)
25 are formed in the workpiece 2. As noted here, according to the first embodiment of the processing apparatus constructed in accordance with the present invention, the deterioration portions of the width W1 and the width W2 can be simultaneously formed, as desired, by the single
30 laser beam application means 6 in the workpiece 2 in two regions displaced in the thickness direction of the workpiece 2.

If the deterioration portions of the width W1 and the width W2 are insufficient to divide the workpiece 2
35 sufficiently precisely along the division line, the

following procedure is recommendable: The laser beam application means 6 and the holding means 4 are moved relative to each other over a predetermined distance in the optical axis direction, namely, in the up-and-down direction in FIG. 1, whereby the focus points 14a and 14b are displaced in the optical axis direction, accordingly, in the thickness direction of the workpiece 2. Further, the laser beam application means 6 and the holding means 4 are moved relative to each other along the division line. In this manner, in addition to the aforementioned formation of the previous deterioration portions, two deterioration portions continuously extending along the division line with the width W1 and the width W2, or many deterioration portions located with spacing along the division line with the width W1 and the width W2 are formed in the workpiece 2 at sites displaced in the thickness direction of the workpiece 2.

FIG. 3 shows another embodiment of a processing apparatus constructed in accordance with the present invention. The processing apparatus illustrated in FIG. 3 comprises holding means 104 for holding a workpiece 102, and laser beam application means 106. The holding means 104 may be of the same configuration as that of the holding means 4 in the embodiment illustrated in FIG. 1.

The laser beam application means 106 in the embodiment shown in FIG. 3 includes pulsed laser beam oscillation means 110, and transmitting/focusing means 112 for transmitting and focusing a pulsed laser beam 114 oscillated by the pulsed laser beam oscillation means 110. The pulsed laser beam oscillation means 110 may be substantially the same as the pulsed laser beam oscillation means 10 shown in FIG. 1. The transmitting/focusing means 112 in the embodiment illustrated in FIG. 3 includes a half mirror 116 functioning as a first splitter, a half mirror 117

functioning as a second splitter, a mirror 118, a mirror 119, a mirror 120, a mirror 121, a half mirror 122, a half mirror 123, first diameter changing means 124, second diameter changing means 125, first optical path length increasing means 126, second optical path length increasing means 127, and a common focusing lens 132. Each of the first diameter changing means 124 and the second diameter changing means 125 may be substantially the same as the diameter changing means 24 shown in FIG. 1, and each of the first optical path length increasing means 126 and the second optical path length increasing means 127 may be of substantially the same configuration as that of the optical path length increasing means 26 shown in FIG. 1. (However, as will be further mentioned later, the optical path length increased by the first optical path length increasing means 126, and the optical path length increased by the second optical path length increasing means 127 need to be different by a required length.)

In the embodiment shown in FIG. 3, the pulsed laser beam 114 from the pulsed laser beam oscillation means 110 is separated into a first pulsed laser beam 114a which passes through the half mirror 116 and advances straightly, and a second pulsed laser beam 114b which is reflected by the half mirror 116 and changed in direction to a substantially perpendicular direction. The first pulsed laser beam 114a passes through the half mirror 117, and advances. During this motion, a third pulsed laser beam 114c, which is reflected by the half mirror 117 substantially perpendicularly, is separated from the first laser beam 114a. The first pulsed laser beam 114a passes through the diameter changing means 124, and thereby has its diameter changed, more specifically, is converted into a form in which its diameter gradually increases as the first pulsed laser beam 114a goes farther from the diameter changing means 124. Then, the first pulsed laser

beam 114a passes through the half mirrors 122 and 123, and is focused by the focusing lens 132 to a focus point 134a in the workpiece 102. The second pulsed laser beam 114b is reflected by the mirror 118 and the mirror 119 to be
5 changed in direction to a substantially perpendicular direction at each time, and then passes through the diameter changing means 125, thereby having its diameter changed, more specifically, being converted into a form in which its diameter gradually increases as the second
10 pulsed laser beam 114b goes farther from the diameter changing means 125. Then, the second pulsed laser beam 114b is reflected by the half mirror 123 to be changed in direction to a substantially perpendicular direction, and is thereby brought into a state where its optical axis
15 aligns with the optical axis of the first pulsed laser beam 114a. Then, the second pulsed laser beam 114b is focused by the focusing lens 132 to a focus point 134b in the workpiece 102. The third pulsed laser beam 114c is reflected by the mirror 120, the mirror 121 and the half
20 mirror 122 to be changed in direction to a substantially perpendicular direction at each time, and is thereby brought into a state where its optical axis aligns with the optical axis of the first laser beam 114a. Then, the third pulsed laser beam 114c passes through the half
25 mirror 123, and is focused by the focusing lens 132 to a focus point 134c in the workpiece 102. The focus point 134a, the focus point 134b, and the focus point 134c are displaced in the optical axis direction of the first pulsed laser beam 114a, the second pulsed laser beam 114b,
30 and the third pulsed laser beam 114c. In addition, the second pulsed laser beam 114b passes through the first optical path length increasing means 126, and is thereby focused to the focus point 134b later by a required time difference Δt_1 than the first pulsed laser beam 114a being
35 focused to the focus point 134a. The third pulsed laser

beam 114c passes through the second optical path length increasing means 127, and is thereby focused to the focus point 134c later by a required time difference dt_2 than the second pulsed laser beam 114b being focused to the focus point 134b. As shown in FIG. 4, these time differences dt_1 and dt_2 are preferably arranged such that the first pulsed laser beam 114a focused to the focus point 134a, the second pulsed laser beam 114b focused to the focus point 134b, and the third pulsed laser beam 114c focused to the focus point 134c are sequentially focused without overlapping each other in terms of time.

In the processing apparatus shown in FIG. 3, deterioration portions are formed in the workpiece 102, as required, in the vicinity of the focus points 134a, 134b and 134c, usually, in regions having some width W_1 , some width W_2 and some width W_3 from the focus points 134a, 134b and 134c upwards. After the first pulsed laser beam 114a is focused to the focus point 134a, the second pulsed laser beam 114b is focused to the focus point 134b. Thus, the deterioration in the region having the width W_2 does not inhibit the focusing of the first pulsed laser beam 114a. After the second pulsed laser beam 114b is focused to the focus point 134b, the third pulsed laser beam 114c is focused to the focus point 134c. Thus, the deterioration in the region having the width W_3 does not inhibit the focusing of the second pulsed laser beam 114b. Thus, the required deterioration can be generated in the respective regions having the widths W_1 , W_2 and W_3 . When the laser beam application means 106 and the holding means 104 are relatively moved along the division line extending, for example, in the right-and-left direction in FIG. 3, three deterioration portions continuously extending along the division line with the width W_1 , the width W_2 and the width W_3 , or many deterioration portions located with spacing along the division line with the width W_1 , the

width W2 and the width W3 are formed in the workpiece 102. If the deterioration portions of the width W1, the width W2 and the width W3 are insufficient to divide the workpiece 102 sufficiently precisely along the division
5 line, the following procedure is recommendable: The laser beam application means 106 and the holding means 104 are moved relative to each other over a predetermined distance in the optical axis direction, namely, in the up-and-down direction in FIG. 3, whereby the focus points 134a, 134b
10 and 134c are displaced in the optical axis direction, accordingly, in the thickness direction of the workpiece 102. Further, the laser beam application means 106 and the holding means 104 are moved relative to each other along the division line. In this manner, in addition to
15 the aforementioned formation of the previous deterioration portions, three deterioration portions continuously extending along the division line with the width W1, the width W2 and the width W3, or many deterioration portions located with spacing along the division line with the
20 width W1, the width W2 and the width W3 are formed in the workpiece 102 at sites displaced in the thickness direction of the workpiece 102.

What we claim is:

1. A processing apparatus using a laser beam, which comprises holding means for holding a workpiece, and laser
5 beam application means for irradiating said workpiece, held by said holding means, with a pulsed laser beam capable of passing through said workpiece, thereby deteriorating said workpiece, said laser beam application means including pulsed laser beam oscillation means and
10 transmitting/focusing means for transmitting and focusing the pulsed laser beam oscillated by said pulsed laser beam oscillation means, wherein
said transmitting/focusing means focuses the pulsed laser beam, with a time difference provided, to at least
15 two focus points displaced in an optical axis direction of the pulsed laser beam.
2. The processing apparatus using a laser beam according to claim 1, wherein said transmitting/focusing
20 means focuses the laser beam to the focus point at a longer distance from said pulsed laser beam oscillation means earlier than the focus point at a shorter distance from said pulsed laser beam oscillation means.
- 25 3. The processing apparatus using a laser beam according to claim 2, wherein the time difference during focusing between the focus points adjacent in the optical axis direction is not smaller than one pulse duration of the pulsed laser beam, but not larger than a time interval
30 between successive pulses of the pulsed laser beam.
4. The processing apparatus using a laser beam according to claim 1, wherein said transmitting/focusing means includes a splitter for dividing the pulsed laser
35 beam from said pulsed laser beam oscillation means into a

first pulsed laser beam and a second pulsed laser beam, a plurality of mirrors for aligning an optical axis of said second pulsed laser beam with an optical axis of said first pulsed laser beam, diameter changing means for
5 changing a diameter of one of said first pulsed laser beam and said second pulsed laser beam, and a common focusing lens.

5. The processing apparatus using a laser beam
10 according to claim 4, wherein said transmitting/focusing means includes optical path length increasing means for increasing an optical path length of one of said first pulsed laser beam and said second pulsed laser beam.

15 6. The processing apparatus using a laser beam according to claim 5, wherein said optical path length increasing means includes an optical fiber.

7. The processing apparatus using a laser beam
20 according to claim 5, wherein said optical path length increasing means includes a plurality of mirrors.