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(54) METHOD OF PROCESSING WAFER

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(57) ABSTRACT

A method of processing a wafer includes a plasma activation processing step of performing plasma processing on at least either one surface of a first wafer or one surface of a second wafer to activate the surface, a bonded wafer forming step of forming a bonded wafer by provisionally joining the first wafer and the second wafer, a modified layer forming step of forming modified layers in an annular pattern inside the first wafer by applying a laser beam of a wavelength having transmissivity for the first wafer, an outer peripheral region removal step of removing an outer peripheral region of the first wafer by applying an external force, an anneal processing step of performing anneal processing to increase joint strength of the bonded wafer, and a grinding step of grinding the first wafer to thin it to a finish thickness.

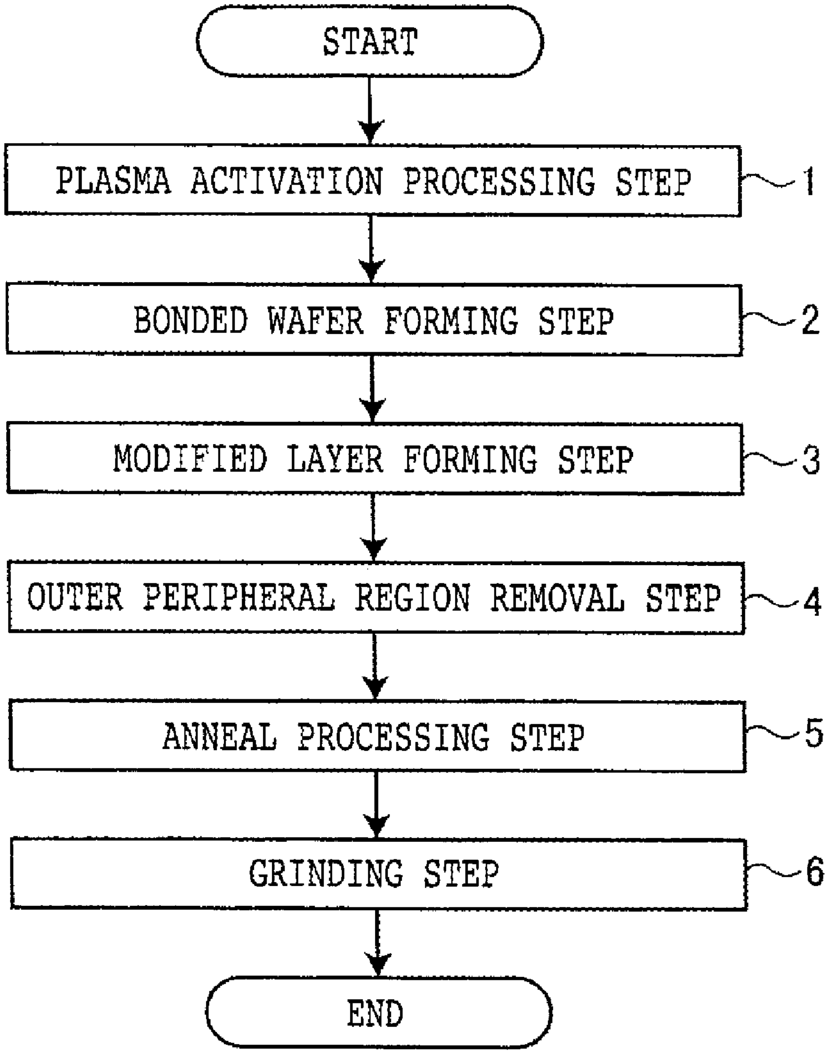


FIG. 1

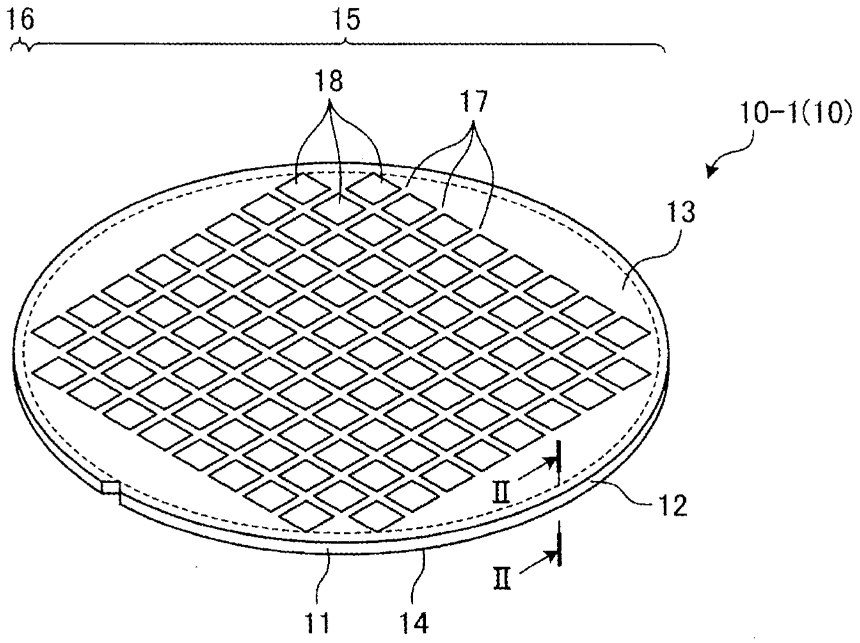


FIG. 2

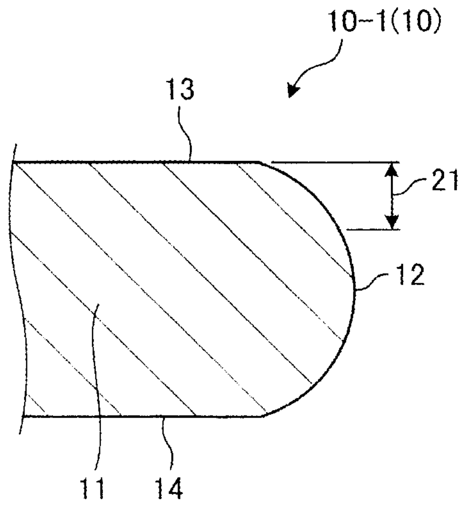


FIG.3

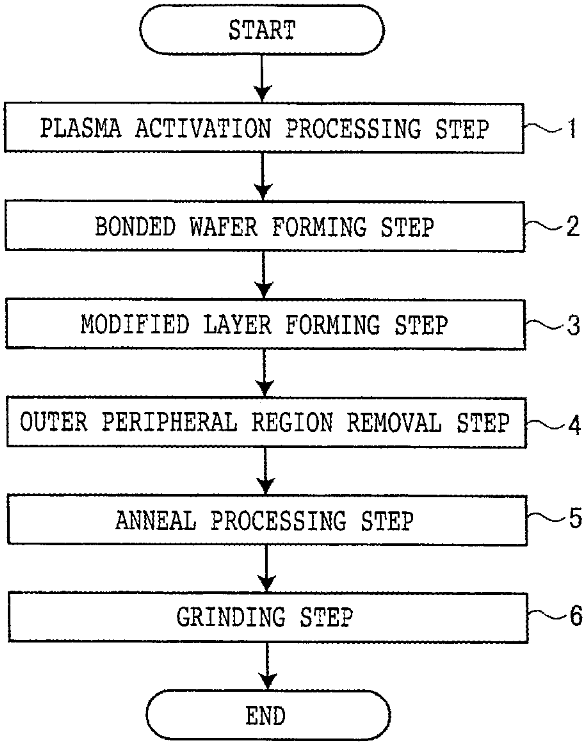

START
PLASMA ACTIVATION PROCESSING STEP
1
BONDED WAFER FORMING STEP
2
MODIFIED LAYER FORMING STEP
3
OUTER PERIPHERAL REGION REMOVAL STEP
4
ANNEAL PROCESSING STEP
5
GRINDING STEP
6
END

FIG.4

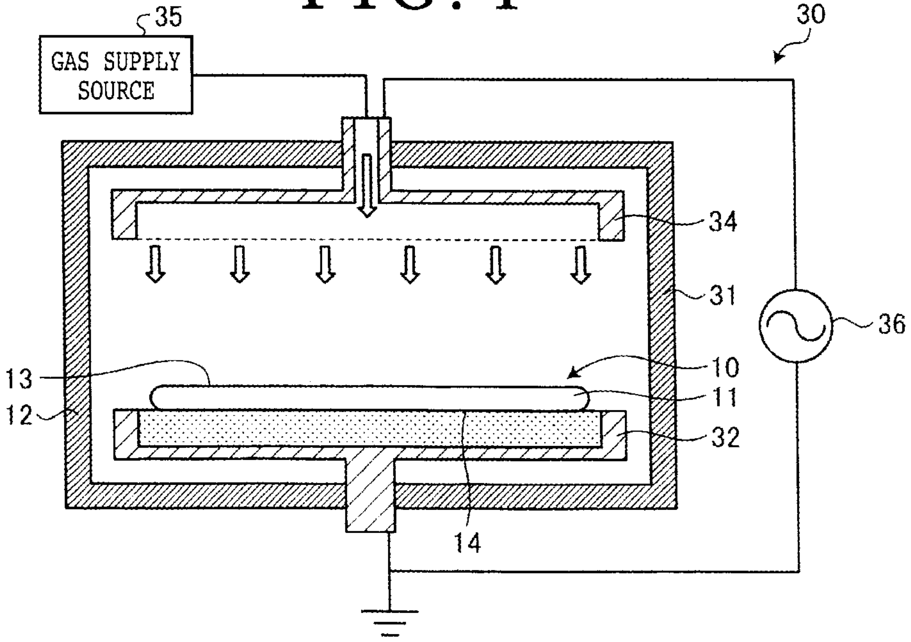

35
GAS SUPPLY SOURCE
30
34
31
36
13
10
11
12
32
14

FIG.5

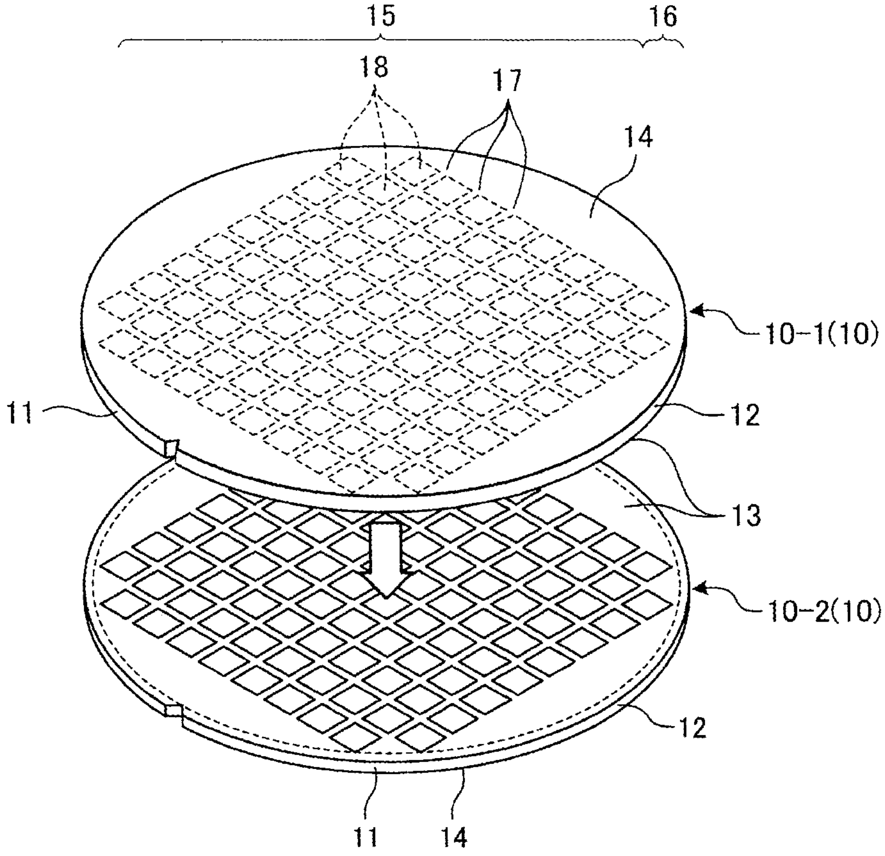

15
16
18
17
14
10-1(10)
11
12
13
10-2(10)
12
11
14

FIG.6

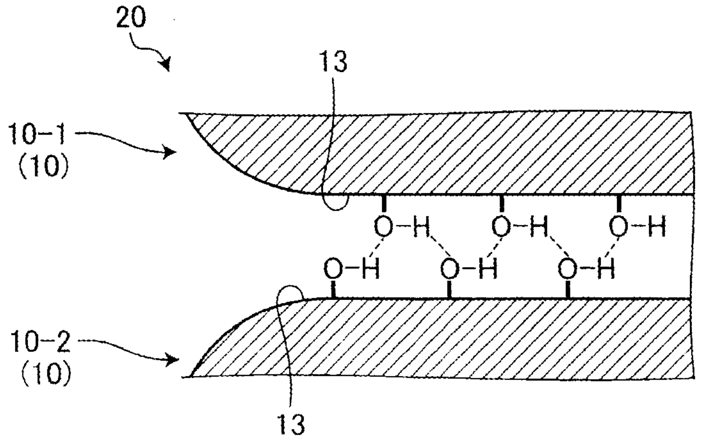

20
13
10-1
(10)
O-H
O-H
O-H
O-H
O-H
O-H
10-2
(10)
13

FIG.7

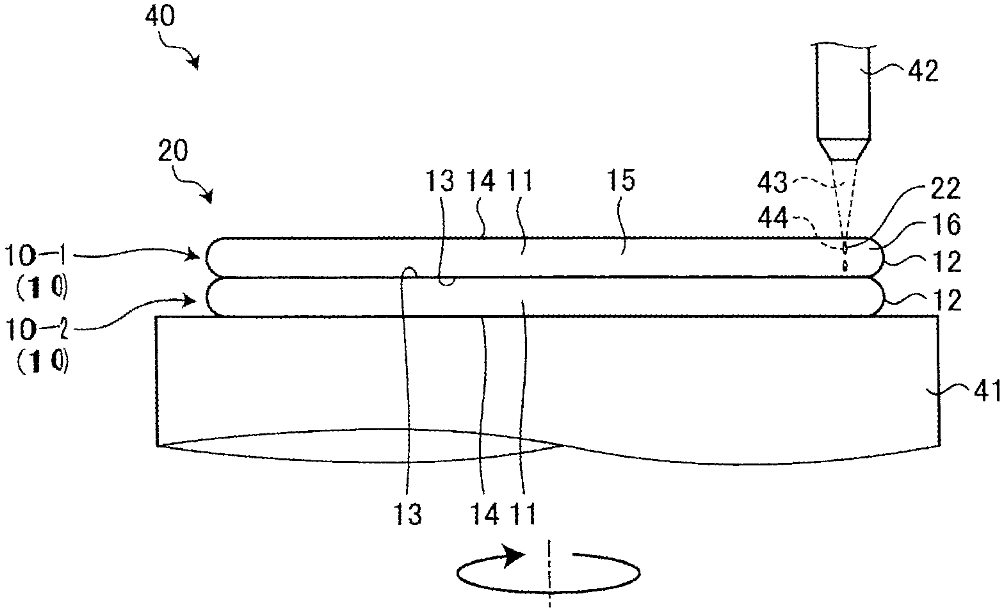

40
42
20
13 14 11
15
43
22
44
16
10-1
(10)
12
10-2
(10)
12
41
13
14 11

FIG.8

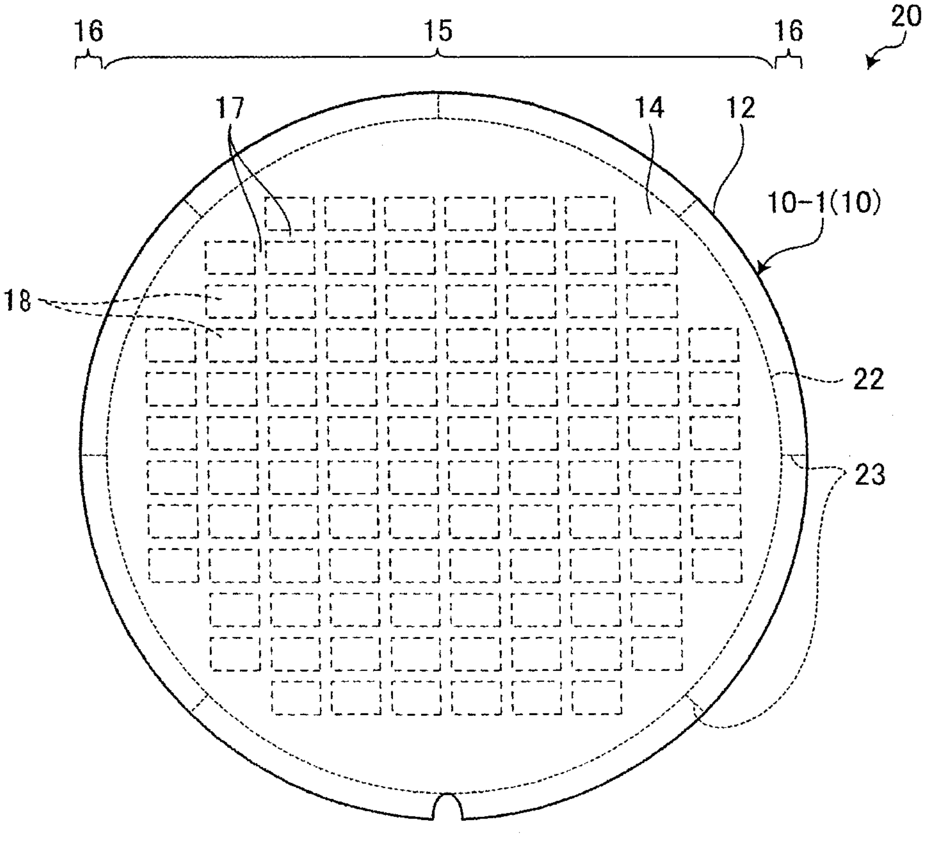

16
15
16
20
17
14
12
10-1(10)
18
22
23

FIG.9

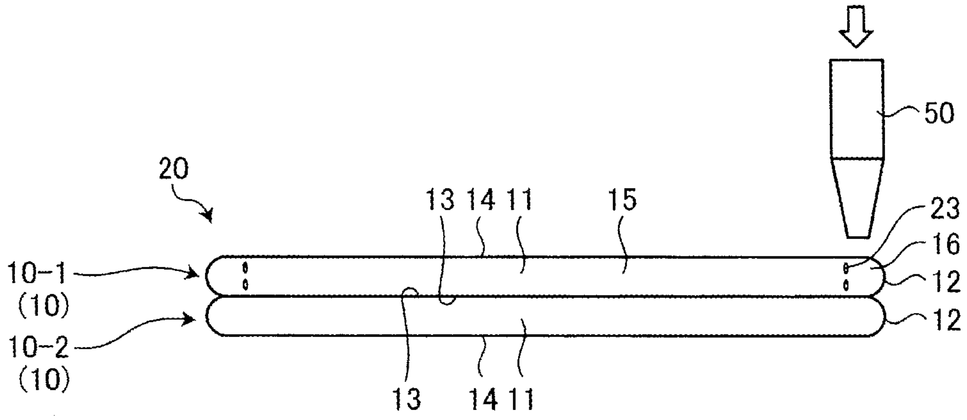

50
20
13 14 11
15
23
16
12
10-1
(10)
10-2
(10)
12
13
14 11

FIG.10

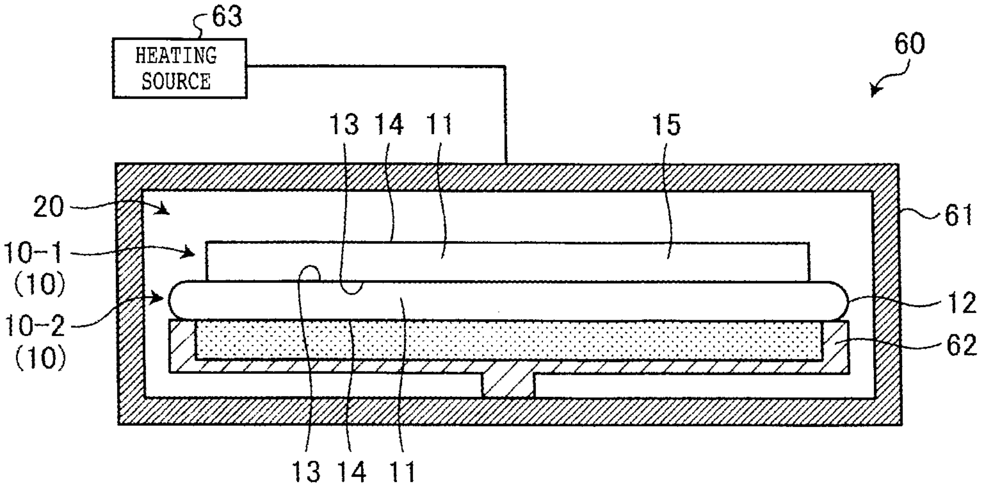

63
HEATING
SOURCE
60
13 14 11
15
20
61
10-1
(10)
10-2
(10)
12
62
13 14 11

FIG.11

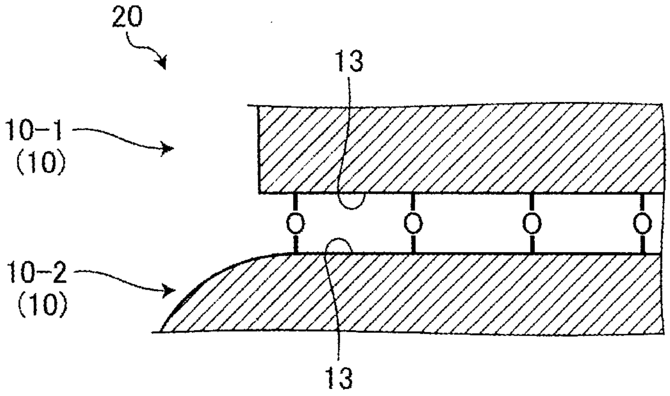

20
13
10-1
(10)
10-2
(10)
13

FIG.12

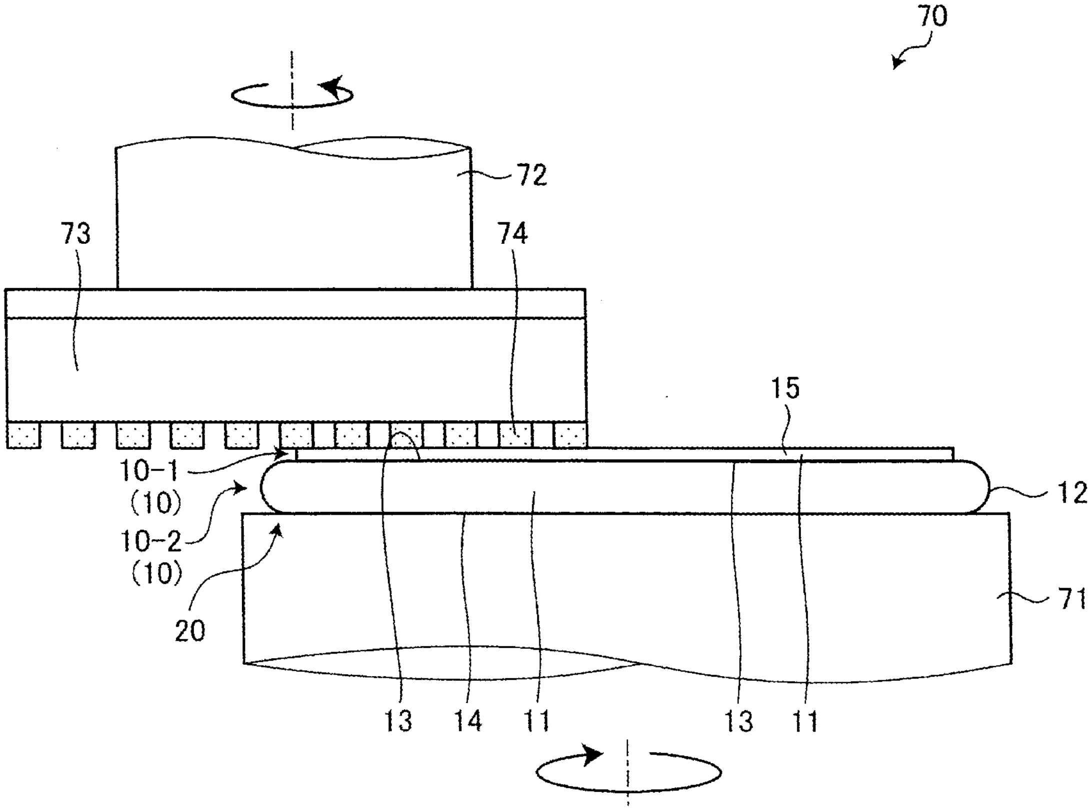
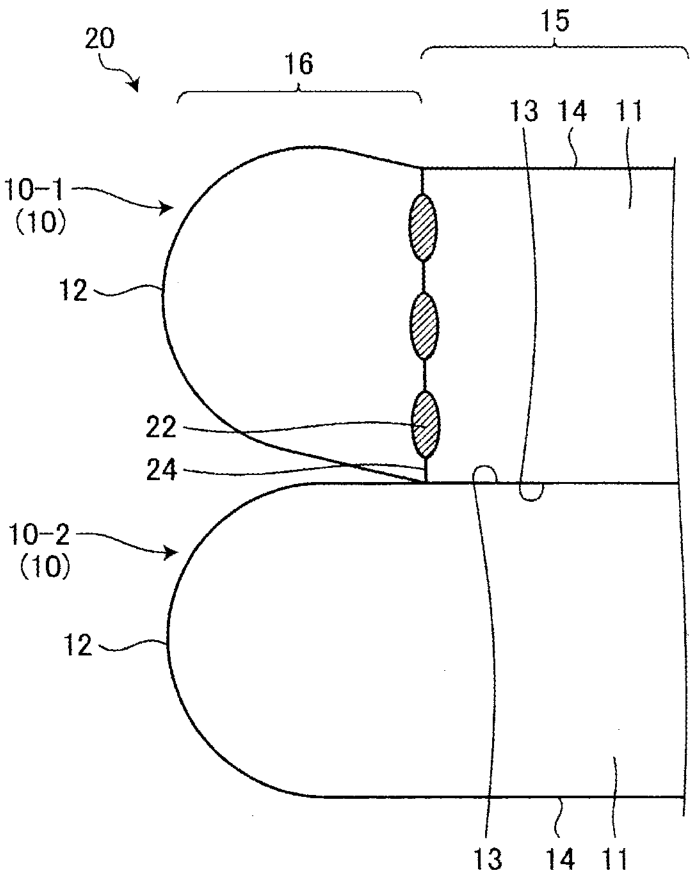

70
72
73
74
15
10-1
(10)
10-2
(10)
12
20
71
13
14
11
13
11

FIG. 13



METHOD OF PROCESSING WAFER

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a method of processing a wafer.

Description of the Related Art

[0002] Keeping in step with the move toward low-profile and high-integration device chips in recent years, development of three-dimensionally stacked semiconductor wafers is under progress. For example, a through-silicon via (TSV) wafer makes it possible to connect electrodes of two chips to each other by bonding both the chips together with through electrodes.

[0003] Such a wafer is thinned by being ground in a state of being bonded to a support wafer which is made of silicon (Si), glass, ceramics, or the like as a substrate. In general, a wafer is chamfered at an outer peripheral edge thereof. When the wafer is ground extremely thin, the outer peripheral edge is thus formed into what is called a knife edge, so that edge chipping is prone to occur during grinding. There is hence a possibility that the chipping may extend to devices and lead to damage to the devices.

[0004] As a measure for a knife edge, what is called an edge trimming technique has been developed to cut an outer peripheral edge of a wafer in an annular profile on a side of a front surface thereof (see JP 4895594B). In addition, an edge trimming method has also been contrived. According to this edge trimming method, a first wafer which has a device region with devices formed therein and a second wafer are bonded together, and a laser beam is then applied to the first wafer along an outer peripheral edge of the device region to form modified layers in an annular pattern inside the first wafer, thereby suppressing the edge chipping, which occurs during grinding of the first wafer, from spreading to the devices (see JP 2020-057709A).

SUMMARY OF THE INVENTION

[0005] However, the method of JP 4895594B has a possibility of causing chipping to occur to such an extent as to reach devices and damaging the devices during grinding, and also involves a problem that the devices are prone to contamination with contaminants due to production of a great deal of grinding debris. Further, the method of JP 2020-057709A has a possibility of causing an edge material of an outer peripheral surplus region, which is to be removed at the time of the grinding, to remain unremoved without separation if the modified layers are formed on a side inner than a joined region between the first wafer and the second wafer.

[0006] The present invention therefore has, as objects thereof, the provision of methods of processing a wafer which can remove such an outer peripheral surplus region while suppressing damage to devices in a step of grinding a bonded wafer.

[0007] In accordance with an aspect of the present invention, there is provided a method of processing a wafer which includes a plasma activation processing step of performing plasma processing on at least either one surface of a first wafer or one surface of a second wafer and thus activating the at least one surface that has been subjected to the plasma processing, to thereby join the first wafer and the second wafer, a bonded wafer forming step of, after performing the plasma activation processing step, forming a bonded wafer by provisionally joining the one surface of the first wafer and the one surface of the second wafer, a modified layer forming step of, after performing the bonded wafer forming step, forming modified layers in an annular pattern inside the first wafer by applying a laser beam of a wavelength having transmissivity for the first wafer, in the annular pattern to the first wafer along a position on a side inner by a predetermined distance than an outer peripheral edge of the first wafer, an outer peripheral region removal step of, after performing the modified layer forming step, removing an outer peripheral region of the first wafer, the outer peripheral region being on a side of the outer peripheral edge relative to the position where the modified layers have been formed in the annular pattern, by applying an external force to the outer peripheral region, an anneal processing step of, after performing the outer peripheral region removal step, performing anneal processing on the bonded wafer to increase joint strength between the first wafer and the second wafer, and a grinding step of, after performing the anneal processing step, grinding the first wafer of the bonded wafer from another surface of the first wafer to thin the first wafer to a predetermined finish thickness.

[0008] In accordance with another aspect of the present invention, there is provided a processing method of processing a wafer which includes a plasma activation processing step of performing plasma processing on at least either one surface of a first wafer or one surface of a second wafer and thus activating the at least one surface that has been subjected to the plasma processing, to thereby join the first wafer and the second wafer, a bonded wafer forming step of, after performing the plasma activation processing step, forming a bonded wafer by provisionally joining the one surface of the first wafer and the one surface of the second wafer, a modified layer forming step of, after performing the bonded wafer forming step, forming modified layers in an annular pattern inside the first wafer and also forming cracks in such a manner as to spread from the modified layers and appear on the one surface of the first wafer, by applying a laser beam of a wavelength having transmissivity for the first wafer, in the annular pattern to the first wafer along a position on a side inner by a predetermined distance than an outer peripheral edge of the first wafer, an anneal processing step of, after performing the modified layer forming step, performing anneal processing on the bonded wafer to increase joint strength between the first wafer and the second wafer, an outer peripheral region removal step of, after performing the anneal processing step, removing an outer peripheral region of the first wafer, the outer peripheral region being on a side of the outer peripheral edge relative to the position where the modified layers have been formed in the annular pattern, by applying an external force to the outer peripheral region, and a grinding step of, after performing the outer peripheral region removal step, grinding the first wafer of the bonded wafer from another surface of the first wafer to thin the first wafer to a predetermined finish thickness.

[0009] Preferably, in the modified layer forming step, the laser beam may be applied a plurality of times to the first wafer with a height position of a focal point of the laser beam changed every time in a thickness direction of the first wafer, such that modified layers are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer.

[0010] Also preferably, in the modified layer forming step, a laser beam having a plurality of focal points apart from one another in a thickness direction of the first wafer may be applied to the first wafer such that modified layers are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer.

[0011] The present invention can remove the outer peripheral surplus region while suppressing damage to the devices in the step of grinding the bonded wafer.

[0012] 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

[0013] FIG. **1** is a perspective view illustrating an example of a wafer to which a method of processing a wafer according to an embodiment of the present invention is to be applied;

[0014] FIG. **2** is a fragmentary cross-sectional view taken along line II-II illustrated in FIG. **1**;

[0015] FIG. **3** is a flow chart illustrating a flow of the method of processing a wafer according to the embodiment;

[0016] FIG. **4** is a partly cross-sectional side view illustrating an example of a plasma activation processing step illustrated in FIG. **3**;

[0017] FIG. **5** is a perspective view illustrating how a bonded wafer forming step illustrated in FIG. **3** is performed;

[0018] FIG. **6** is a fragmentary cross-sectional view schematically illustrating the details of bonding between joined surfaces in a bonded wafer produced by the bonded wafer forming step illustrated in FIG. **3**;

[0019] FIG. **7** is a partly cross-sectional side view illustrating how a modified layer forming step illustrated in FIG. **3** is performed;

[0020] FIG. **8** is a plan view illustrating the bonded wafer that has undergone the modified layer forming step illustrated in FIG. **3**;

[0021] FIG. **9** is a partly cross-sectional side view illustrating an example of an outer peripheral region removal step illustrated in FIG. **3**;

[0022] FIG. **10** is a partly cross-sectional side view illustrating an example of an anneal processing step illustrated in FIG. **3**;

[0023] FIG. **11** is a fragmentary cross-sectional view schematically illustrating the details of bonding between the joined surfaces in the bonded wafer that has undergone the anneal processing step illustrated in FIG. **3**;

[0024] FIG. **12** is a partly cross-sectional side view illustrating how a grinding step illustrated in FIG. **3** is performed; and

[0025] FIG. **13** is a fragmentary cross-sectional view illustrating, on an enlarged scale, a portion of a bonded wafer that has undergone a modified layer forming step in a method of processing a wafer according to a modification of the embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0026] With reference to the attached drawings, an embodiment of the present invention and a modification of the embodiment will hereinafter be described in detail. However, the present invention shall not be limited to the details of the following embodiment and modification. The elements of configurations that will hereinafter be described include those readily conceivable to persons skilled in the art and those substantially the same as ones described below. Further, the configurations that will hereinafter be described can be combined appropriately. Moreover, various omissions, replacements, and modifications of configurations can be made without departing from the spirit of the present invention.

Embodiment

[0027] A method of processing a wafer **10** according to the embodiment of the present invention will be described based on FIGS. **1** to **12**. FIG. **1** is a perspective view illustrating an example of the wafer **10** to which the method of processing a wafer according to the present embodiment is to be applied. FIG. **2** is a fragmentary cross-sectional view taken along line II-II illustrated in FIG. **1**.

[0028] The wafer **10** illustrated in FIGS. **1** and **2** is such a wafer as a disk-shaped semiconductor wafer or optical device that uses Si, sapphire (Al_2O_3), gallium arsenide (GaAs), silicon carbide (SiC), or the like for a substrate **11**, and is an Si wafer in the present embodiment. As illustrated in FIG. **2**, the wafer **10** is chamfered at an outer peripheral edge **12** thereof such that the wafer **10** protrudes most toward an outer periphery at the center in a thickness direction thereof and has a round arc profile in cross-section from a front surface **13** to a back surface **14** of the substrate **11**.

[0029] As illustrated in FIG. **1**, the wafer **10** includes, on the front surface **13** of the substrate **11**, a central region **15** and an outer peripheral region **16** surrounding the central region **15**. The central region **15** has a plurality of division lines **17** set in a grid pattern on the front surface **13** of the substrate **11** and devices **18** formed in respective regions defined by the division lines **17**. The outer peripheral region **16** surrounds the central region **15** over the entirety of a periphery thereof and has no devices **18** formed therein.

[0030] In the present embodiment, the devices **18** constitute three dimensional NOT-AND (3D NAND) flash memories and include electrode pads and through electrodes connected to the electrode pads. When the substrate **11** is thinned and the devices **18** are individually divided from the wafer **10**, the through electrodes extend to the back surface **14** of the substrate **11**. The wafer **10** in the present embodiment is thus what is called a TSV wafer in which the individually formed devices **18** each have through electrodes. However, it is to be noted that the wafer **10** in the present invention is not limited to such a TSV wafer having through electrodes as in the present embodiment and may be a device wafer having no through electrodes.

[0031] FIG. **3** is a flow chart illustrating a flow of the method of processing the wafer **10** according to the embodiment. As illustrated in FIG. **3**, the method of processing the wafer **10** according to the present embodiment includes a plasma activation processing step **1**, a bonded wafer forming step **2**, a modified layer forming step **3**, an outer peripheral region removal step **4**, an anneal processing step **5**, and a grinding step **6**. The method of processing the wafer **10** according to the present embodiment is a method of bonding one surfaces of a pair of wafers **10** together and thinning one of the wafers **10** (first wafer **10-1**) to a predetermined finish thickness **21** (see FIG. **2**). It is to be noted that, in the present embodiment, the one surfaces are the front surfaces **13**.

[0032] It is to be noted that, when the pair of wafers **10** are distinguished from each other in the following description, one wafer **10** will be referred to as the "first wafer **10-1**," and the other wafer **10** will be referred to as a "second wafer **10-2**" (see FIG. **5**). When the wafers **10** are not distinguished from each other, they will simply be referred to as the "wafers **10**." The other wafer **10**, i.e., the second wafer **10-2**, that will not be thinned will be described as a TSV wafer similar to the first wafer **10-1** in the present embodiment, but may also be a simple substrate wafer having no pattern in the present invention.

[0033] FIG. **4** is a partly cross-sectional side view illustrating an example of the plasma activation processing step **1** illustrated in FIG. **3**. To join the first wafer **10-1** and the second wafer **10-2** together, the plasma activation processing step **1** performs plasma processing on each surface to be joined, whereby the surface to which the plasma processing is performed is activated. In the plasma activation processing step **1**, the plasma processing is performed on at least either the one surface of the first wafer **10-1** or the one surface of the second wafer **10-2**.

[0034] In the plasma activation processing step **1** according to the present embodiment, the plasma processing is performed on the front surface **13** of each of the wafers **10** (first wafer **10-1** and second wafer **10-2**) in a plasma processing system **30** illustrated in FIG. **4**. The plasma processing system **30** includes a chamber **31**, a lower electrode **32**, an upper electrode **34**, a gas supply source **35**, and a radio frequency power supply **36**, and also includes an electrostatic attraction system, a lift mechanism, a loading/unloading opening, and an exhaust system, which are not illustrated.

[0035] In the chamber **31**, the lower electrode **32** and the upper electrode **34** are arranged to vertically face each other. The lower electrode **32** is formed of an electrically conductive material and has a disk-shaped holding portion for holding the wafer **10**. Inside the holding portion, the electrostatic attraction system, which is not illustrated, is formed. When the electrostatic attraction system is energized, the wafer **10** placed on an upper surface of the holding portion can be fixed by electrostatic attraction.

[0036] The upper electrode **34** is formed of an electrically conductive material and has a disk-shaped gas ejection portion that covers above the wafer **10** held on the holding portion of the lower electrode **32**. The gas ejection portion is in communication with the gas supply source **35**. The gas supply source **35** supplies a process gas such as argon (Ar), nitrogen (N_2), or oxygen (O_2) into the chamber **31** through the gas ejection portion. The upper electrode **34** is movable up and down relative to the lower electrode **32** by the lift mechanism, which is not illustrated.

[0037] The lower electrode **32** and the upper electrode **34** have respective insulating members, which are not illustrated, between themselves and a bottom wall and top wall of the chamber **31** and are isolated from the chamber **31**. The lower electrode **32** and the upper electrode **34** are connected to the radio frequency power supply **36**. Based on control signals outputted from a controller not illustrated, the radio frequency power supply **36** supplies predetermined radio frequency power to the lower electrode **32** and the upper electrode **34**.

[0038] In the plasma activation processing step **1**, the wafer **10** is first loaded into the chamber **31** from the loading/unloading opening, which is not illustrated, and is placed on the holding portion of the lower electrode **32** such that the front surface **13** of the wafer **10** is directed upward. The electrostatic attraction system, which is not illustrated, is then activated, so that the wafer **10** is electrostatically attracted and held on the holding portion. Further, the loading/unloading opening, which is not illustrated, is closed, so that a processing space in the chamber **31** is hermetically closed. Moreover, the height position of the upper electrode **34** is adjusted by the lift mechanism, which is not illustrated, such that the lower electrode **32** and the upper electrode **34** are brought into a predetermined positional relation suited for the plasma processing.

[0039] In the plasma activation processing step **1**, the exhaust system, which is not illustrated, is next driven to bring the processing space in the chamber **31** to vacuum (low pressure). While the process gas is supplied at a predetermined flow rate from the gas supply source **35** to the processing space in the chamber **31**, the predetermined radio frequency power is then supplied from the radio frequency power supply **36** to the lower electrode **32** and the upper electrode **34**, so that a plasma state gas is supplied to the front surface **13** of the wafer **10**. By performing such plasma processing, surface impurities such as organic matter adsorbed on the front surface **13** of the wafer **10** are removed, and a clean surface is exposed. Further, hydroxyl groups (OH groups) are bound to Si dangling bonds on the exposed, clean front surface **13**. In other words, OH groups are formed on the front surface **13** of the wafer **10** which has been activated by the plasma processing.

[0040] The plasma activation processing step **1** according to the present embodiment is performed on both the front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2** but may be performed on only one of these surfaces.

[0041] FIG. **5** is a perspective view illustrating how the bonded wafer forming step **2** illustrated in FIG. **3** is performed. FIG. **6** is a fragmentary cross-sectional view schematically illustrating the details of bonding between joined surfaces in a bonded wafer **20** produced by the bonded wafer forming step **2** illustrated in FIG. **3**. The bonded wafer forming step **2** is performed after the plasma activation processing step **1** is performed. The bonded wafer forming step **2** forms the bonded wafer **20** by provisionally joining the first wafer **10-1** and the second wafer **10-2** together.

[0042] In the bonded wafer forming step **2**, at least one surface on which OH groups have been formed in the plasma activation processing step **1** is used as a surface to be joined. In the present embodiment, the front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2** are bonded together.

[0043] In the bonded wafer forming step **2**, the front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2** are first brought to face each other with an interval left therebetween. The front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2** are then bonded together. Consequently, the bonded wafer **20** is formed.

[0044] On this occasion, the hydrogen atoms (H) of OH groups formed on the front surface **13** of the first wafer **10-1** form non-covalent hydrogen bonds with the oxygen atoms (O) of OH groups formed on the front surface **13** of the second wafer **10-2**. In parallel with the foregoing, the hydrogen atoms (H) of the OH groups formed on the front surface **13** of the second wafer **10-2** also form non-covalent hydrogen bonds with the oxygen atoms (O) of the OH groups formed on the front surface **13** of the first wafer **10-1**. Consequently, the first wafer **10-1** and the second wafer **10-2** are attracted to each other through the hydrogen bonds and are provisionally joined together.

[0045] FIG. **7** is a partly cross-sectional side view illustrating how the modified layer forming step **3** illustrated in FIG. **3** is performed. FIG. **8** is a plan view illustrating the bonded wafer **20** that has undergone the modified layer forming step **3** illustrated in FIG. **3**. The modified layer forming step **3** is performed after the bonded wafer forming step **2** is performed. The modified layer forming step **3** forms modified layers **22** in an annular pattern along a position on a side inner by a predetermined distance than the outer peripheral edge **12** of the first wafer **10-1**. In the modified layer forming step **3**, the modified layers **22** are formed inside the first wafer **10-1** through stealth dicing by a laser processing apparatus **40**.

[0046] The laser processing apparatus **40** includes a holding table **41** and a laser beam applying unit **42**. The holding table **41** holds the wafers **10** on a holding surface thereof and is rotatable about a vertical axis of rotation. The laser beam applying unit **42** applies a laser beam **43** to the first wafer **10-1** held on the holding table **41** via the second wafer **10-2**. The laser processing apparatus **40** further includes a moving unit, which is not illustrated, for moving the holding table **41** and the laser beam applying unit **42** relative to each other and an imaging unit, which is not illustrated, for imaging the first wafer **10-1** held on the holding table **41** via the second wafer **10-2**, for example.

[0047] In the modified layer forming step **3**, the modified layers **22** are formed in the annular pattern by the laser beam **43** applied along the position on the side inner by the predetermined distance than the outer peripheral edge **12** of the first wafer **10-1**. The position on the side inner by the predetermined distance than the outer peripheral edge **12** represents a boundary between the central region **15** and the outer peripheral region **16**. The laser beam **43** is a laser beam of a wavelength having transmissivity for the first wafer **10-1** and is, for example, infrared rays (IR).

[0048] The modified layers **22** represent regions each of which has one or more of the density, refractive index, mechanical strength, and other physical properties having changed to a level or levels different from the corresponding one or ones of surrounding regions. Each modified layer **22** is, for example, a fusion treated region, a cracked region, a dielectric breakdown region, a refractive index change region, or a region where two or three of these regions exist mixed together. The modified layers **22** are lower in mechanical strength or the like than the other regions in the first wafer **10-1**.

[0049] In the modified layer forming step **3**, the back surface **14** of the second wafer **10-2** is first held under suction on the holding surface (upper surface) of the holding table **41**. An alignment is then performed between the first wafer **10-1** and a condenser of the laser beam applying unit **42**. Described specifically, the holding table **41** is moved by the moving unit, which is not illustrated, to an application region below the laser beam applying unit **42**. The first wafer **10-1** is then imaged by the imaging unit, which is not illustrated, followed by an alignment to make an application portion of the laser beam applying unit **42** face, in a vertical direction, the position inner by the predetermined distance than the outer peripheral edge **12** of the first wafer **10-1**, and then to set a focal point **44** of the laser beam **43** inside the first wafer **10-1**.

[0050] In the modified layer forming step **3**, the laser beam applying unit **42** then applies the laser beam **43** to the first wafer **10-1** from the back surface **14** thereof while the holding table **41** is rotating about the vertical axis of rotation. The laser beam **43** is thus applied in the annular pattern along the position inner by the predetermined distance than the outer peripheral edge **12** of the first wafer **10-1**, so that the modified layers **22** are formed in the annular pattern.

[0051] At this time, in the modified layer forming step **3**, the laser beam **43** may be applied a plurality of times to the first wafer **10-1** with a height position of the focal point **44** of the laser beam **43** changed every time in the thickness direction of the first wafer **10-1**. As an alternative, the laser beam **43** may have a plurality of focal points **44** apart from one another in the thickness direction of the first wafer **10-1** and may be applied to the first wafer **10-1** such that modified layers **22** are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer **10-1**. Cracks spread from the modified layers **22**, and by interconnections between the modified layers and the cracks, division start points are formed in the annular pattern at the position inner by the predetermined distance than the outer peripheral edge **12** of the first wafer **10-1**.

[0052] As illustrated in FIG. **8**, in the modified layer forming step **3** according to the present embodiment, additional modified layers **23** may further be formed to section the outer peripheral region **16**, which is on a side of the outer peripheral edge **12** relative to the modified layers **22** in the first wafer **10-1**, into at least two or more sub-regions. In the modified layer forming step **3**, a plurality of, e.g., seven, additional modified layers **23** are radially formed in line patterns between an inner peripheral edge of the outer peripheral region **16** and the outer peripheral edge **12** at positions spaced at predetermined intervals in a peripheral direction in the outer peripheral region **16** of the first wafer **10-1**.

[0053] In this case, the holding table **41** is moved such that the focal point **44** of the laser beam **43** moves toward a radially outer side of the first wafer **10-1**. That is, by the laser beam **43** applied in the radial direction to the outer peripheral region **16**, the additional modified layers **23** are formed along the radial direction. As an alternative, the laser beam **43** may be applied to the outer peripheral region **16** while the holding table **41** is moved such that the focal point **44** moves from the radially outer side toward a radially inner side of the first wafer **10-1**. If this is the case, the application of the laser beam **43** is stopped upon arrival of the focal point **44** at the modified layers **22**.

[0054] It is to be noted that the additional modified layers **23** illustrated in FIG. **8** section, along with a notch indicating a crystal orientation, the outer peripheral region **16** into eight sub-regions in the peripheral direction. In the present invention, however, the additional modified layers **23** may further section the outer peripheral region **16** into, for example, sixteen sub-regions, which is twice as many as the sectioning described above, in the peripheral direction, and/or may include additional modified layers **23** formed in annular patterns to section the outer peripheral region **16** into a plurality of sub-regions in the radial direction. The number of such sectioning may appropriately be set according to the diameter of the first wafer **10-1** and the width dimension of its outer peripheral region **16**.

[0055] As in the formation of the modified layers **22**, when forming such additional modified layers **23**, the laser beam **43** may also be applied a plurality of times to the first wafer **10-1** with the height position of the focal point **44** of the laser beam **43** changed every time in the thickness direction of the first wafer **10-1**. As an alternative, the laser beam **43** may have a plurality of focal points **44** apart from one another in the thickness direction of the first wafer **10-1** and may be applied to the first wafer **10-1** such that additional modified layers **23** are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer **10-1**.

[0056] FIG. **9** is a partly cross-sectional side view illustrating an example of the outer peripheral region removal step **4** illustrated in FIG. **3**. The outer peripheral region removal step **4** is performed after the modified layer forming step **3** is performed. The outer peripheral region removal step **4** applies an external force to the outer peripheral region **16** of the first wafer **10-1**, the outer peripheral region **16** being on the side of the outer peripheral edge **12** relative to the position where the modified layers **22** have been formed in the annular pattern, to remove the outer peripheral region **16**. In the outer peripheral region removal step **4** according to the present embodiment, the outer peripheral region **16** is removed by a shear force applied from a pressing member **50** in the thickness direction of the first wafer **10-1**.

[0057] The pressing member **50** is movable in an up-down direction and applies the external force by pressing the first wafer **10-1** of the bonded wafer **20** from above and applying a downward load to the first wafer **10-1**. In the outer peripheral region removal step **4**, the bonded wafer **20** is first placed on a holding table, which is not illustrated, such that the first wafer **10-1** is located above. The pressing member **50** is then lowered in a state of facing the outer peripheral region **16** of the first wafer **10-1** in a vertical direction, so that the pressing member **50** is pressed against the outer peripheral region **16** of the first wafer **10-1** to apply a load.

[0058] Consequently, a downward external force is applied to the outer peripheral region **16** by the pressing member **50**. Using the modified layers **22** and the cracks as start points, the central region **15** and the outer peripheral region **16** are divided, so that the outer peripheral region **16** of the first wafer **10-1** is removed.

[0059] FIG. **10** is a partly cross-sectional side view illustrating an example of the anneal processing step **5** illustrated in FIG. **3**. FIG. **11** is a fragmentary cross-sectional view schematically illustrating the details of bonding between the joined surfaces in the bonded wafer **20** that has undergone the anneal processing step **5** illustrated in FIG. **3**. The anneal processing step **5** is performed after the outer peripheral region removal step **4** is performed. The anneal processing step **5** increases joint strength between the first wafer **10-1** and the second wafer **10-2** by performing anneal processing on the bonded wafer **20**.

[0060] The anneal processing step **5** according to the present embodiment is performed in an anneal processing system **60**. The anneal processing system **60** includes a chamber **61**, a holding table **62**, and a heating source **63**. In the chamber **61**, the holding table **62** is arranged. The holding table **62** can hold the bonded wafer **20** under suction on a holding surface thereof. The chamber **61** is internally heated by the heating source **63**. The heating source **63** includes, for example, infrared lamps. The holding table **62** may internally have another heating source to heat the bonded wafer **20** held on the holding surface of the holding table **62**.

[0061] In the anneal processing step **5** according to the present embodiment, the bonded wafer **20** is first loaded from a loading/unloading opening, which is not illustrated, into the chamber **61** and is held on the holding table **62**. The heating source **63** is then energized to heat the inside of the chamber **61**. The wafers **10** in the present embodiment are Si wafers and thus easily absorb infrared rays. When heated by the heating source **63** including the infrared lamps, the bonded wafer **20** is rapidly heated. It is to be noted that such a heating method is called rapid thermal anneal (RTA).

[0062] On the bonded surfaces of the first wafer **10-1** and the second wafer **10-2** of the bonded wafer **20** thus heated, a dehydro-condensation reaction occurs. Described specifically, water (H_2O) molecules are lost from OH groups formed on the front surfaces **13**, so that covalent bonds are formed via oxygen atoms (O) as illustrated in FIG. **11**. This leads to an improvement in joint strength between the front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2**.

[0063] FIG. **12** is a partly cross-sectional side view illustrating how the grinding step **6** illustrated in FIG. **3** is performed. The grinding step **6** is performed after the anneal processing step **5** is performed. The grinding step **6** grinds the first wafer **10-1** of the bonded wafer **20** from the back surface **14** to thin the first wafer **10-1** to the predetermined finish thickness **21** (see FIG. **2**). In other words, the first wafer **10-1** is thinned to the predetermined finish thickness **21** by being ground on the back surface **14** with a grinding apparatus **70**.

[0064] The grinding apparatus **70** includes a holding table **71**, a spindle **72** as a rotating shaft member, a grinding wheel **73** attached to a lower end of the spindle **72**, grinding stones **74** secured to a lower surface of the grinding wheel **73**, and a grinding fluid supply unit, which is not illustrated. The grinding wheel **73** rotates about an axis of rotation which is parallel to an axis of rotation of the holding table **71**.

[0065] In the grinding step **6**, the back surface **14** of the second wafer **10-2** is first held under suction on a holding surface of the holding table **71**. With the holding table **71** rotating about its axis of ration, the grinding wheel **73** is rotated about its axis of rotation. A grinding fluid is supplied to a processing point by the grinding fluid supply unit, which is not illustrated, and at the same time, the grinding stones **74** of the grinding wheel **73** are brought closer at a predetermined feed rate toward the holding table **71**, whereby the first wafer **10-1** is ground on the back surface **14** thereof by the grinding stones **74** and is thinned to the predetermined finish thickness **21** (see FIG. **2**).

[0066] As described above, in the method of processing the wafer **10** according to the present embodiment, after the pair of wafers **10** is bonded to each other by a provisional joint through hydrogen bonds, the outer peripheral region **16** of the wafer **10** (first wafer **10-1**) that is later to be ground to the predetermined finish thickness **21** is removed, and the joint strength is increased by anneal processing before the grinding. This makes it possible to remove the outer peripheral region **16** on the side of the outer peripheral edge **12** relative to the modified layers **22**, which are formed in the annular pattern, in a state that the joint strength is weak, and hence, the outer peripheral region **16** can be removed easily and reliably compared with before.

[0067] Further, in the method of processing the wafer **10** according to the present embodiment, the step of forming the modified layers **22** in the annular pattern as division start points to remove the outer peripheral region **16** (modified layer forming step **3**) is performed after the step of bonding the wafers **10** to each other (bonded wafer forming step **2**). This can provide a cleaner step because processing debris produced upon the formation of the modified layers does not scatter on the bonded surfaces. In addition, a risk such as edge chipping which tends to occur upon a transfer of the wafers **10** can be suppressed because there is no need to transfer the wafers **10** to bond them together after the formation of the modified layers **22**.

[0068] Moreover, cracks should not be formed to appear on both the front surface **13** and the back surface **14** of the first wafer **10-1** if the modified layers are formed in the annular pattern before the first wafer **10-1** and the second wafer **10-2** are bonded together. After the bonding, however, cracks may be formed to appear both the surfaces, so that the removal of the outer peripheral region **16** is facilitated.

Modification

[0069] FIG. **13** is a fragmentary cross-sectional view illustrating, on an enlarged scale, a portion of a bonded wafer **20** that has undergone a modified layer forming step **3** (see FIG. **3**) in a method of processing the wafer **10** according to a modification of the above-described embodiment. As illustrated in FIG. **13**, cracks **24** spread from the respective modified layers **22** along a boundary between the central region **15** and the outer peripheral region **16**, and the cracks **24** thus spread appear on the front surface **13** and the back surface **14** of the first wafer **10-1**. It is to be noted that, in the modification, the modified layers **22** may be formed to cause cracks **24** to appear on at least the front surface **13**.

[0070] In association with the formation of the modified layers **22** and the cracks **24**, the first wafer **10-1** blisters at the boundary between the central region **15** and the outer peripheral region **16**. As a result, the first wafer **10-1** produces a warp to protrude on the front surface **13** at the outer peripheral region **16** on the side of the outer peripheral edge **12** relative to the modified layers **22** and the cracks **24**. This causes the joint, i.e., the provisional joint, between the front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2** to separate at the outer peripheral region **16**. Here, the removal of the outer peripheral region **16** is easier if the cracks **24** appear on both the front surface **13** and the back surface **14** rather than appearing on the front surface **13** only.

[0071] The method of processing the wafer **10** according to the present modification is different from the method of processing the wafer **10** according to the embodiment in that the outer peripheral region removal step **4** and the anneal processing step **5** are reversed in order. Described specifically, the anneal processing step **5** is performed after the modified layer forming step **3** is performed, the outer peripheral region removal step **4** is performed after the anneal processing step **5** is performed, and the grinding step **6** is performed after the outer peripheral region removal step **4** is performed.

[0072] As the joint, i.e., the provisional joint, between the front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2** has separated at the outer peripheral region **16** in the modified layer forming step **3**, the joint between the front surface **13** of the first wafer **10-1** and the front surface **13** of the second wafer **10-2** fails to provide sufficient bonding at the outer peripheral region **16** despite the occurrence of the dehydro-condensation reaction in the succeeding anneal processing step **5**. In the outer periphery removal step **4** that is performed next, the outer peripheral region **16** can thus be prevented from remaining on the first wafer **10-1** due to a joint that would be formed with the second wafer **10-2** if the above-described separation did not occur.

[0073] As described above, in the method of processing the wafer **10** according to the modification, a warp is produced at the outer peripheral region **16** of the first wafer **10-1** in the modified layer forming step **3** to cause the first wafer **10-1** and the second wafer **10-2** to fail to provide sufficient bonding. The outer peripheral region **16** can hence be removed despite the anneal processing step **5** is performed before the outer peripheral region removal step **4**. By performing the outer peripheral region removal step **4** after the anneal processing step **5** as described above, the bonded wafer **20** in the provisionally joined state can be prevented from moving during removal of the outer peripheral region **16** of the first wafer **10-1** or from causing air to penetrate to the joined surfaces.

[0074] It is to be noted that the present invention shall not be limited to the above-described embodiment and modification. In other words, the present invention can be practiced with various modifications within the scope not departing from the spirit of the present invention.

[0075] In the plasma activation processing step **1** according to the embodiment, in order to perform the plasma processing, the pressure in the chamber **31** is reduced to generate a plasma. However, the method of performing the plasma processing is not limited to such a vacuum plasma method as described above in the embodiment and may be, for example, an open-type atmospheric pressure plasma method of scanning the wafer **10** in its plane with a plasma generating electrode during a standby period with the wafer **10** placed on a stage.

[0076] Further, in the outer peripheral region removal step **4** according to the embodiment, the outer peripheral region **16** of the first wafer **10-1** is pressed from above to apply the external force in a shear direction. However, the method of applying the external force is not limited to the above-described method, and may be a method of applying the external force in the shear direction by lifting up the outer peripheral region **16** of the first wafer **10-1** or a method of crushing the outer peripheral region **16** of the first wafer **10-1** between rollers. Without being limited to a mechanical external force, the external force may also be vibrations generated by ultrasonic waves or an external force generated in a radial direction by expanding an expandable tape bonded to the back surface **14** of the first wafer **10-1**.

[0077] Moreover, in the anneal processing step **5** according to the embodiment, single wafer RTA is performed to rapidly heat a plurality of bonded wafers **20** one after one in the chamber **61**. However, the method of performing the anneal processing on the bonded wafer **20** is not limited to the above-described method and may be a batch-type anneal processing method of concurrently performing a heat treatment on a plurality of bonded wafers **20** arranged, for example, in a quartz furnace tube, by heating them from outside. In addition, the anneal processing method is not limited to a method of heating the bonded wafer **20** by infrared rays and may be a method of heating the bonded wafer **20** on a hot plate.

[0078] 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 method of processing a wafer, comprising:

a plasma activation processing step of performing plasma processing on at least either one surface of a first wafer or one surface of a second wafer and thus activating the at least one surface that has been subjected to the plasma processing, to thereby join the first wafer and the second wafer;

a bonded wafer forming step of, after performing the plasma activation processing step, forming a bonded wafer by provisionally joining the one surface of the first wafer and the one surface of the second wafer;

a modified layer forming step of, after performing the bonded wafer forming step, forming modified layers in an annular pattern inside the first wafer by applying a laser beam of a wavelength having transmissivity for the first wafer, in the annular pattern to the first wafer along a position on a side inner by a predetermined distance than an outer peripheral edge of the first wafer;

an outer peripheral region removal step of, after performing the modified layer forming step, removing an outer peripheral region of the first wafer, the outer peripheral region being on a side of the outer peripheral edge relative to the position where the modified layers have been formed in the annular pattern, by applying an external force to the outer peripheral region;

an anneal processing step of, after performing the outer peripheral region removal step, performing anneal processing on the bonded wafer to increase joint strength between the first wafer and the second wafer; and

a grinding step of, after performing the anneal processing step, grinding the first wafer of the bonded wafer from another surface of the first wafer to thin the first wafer to a predetermined finish thickness.

2. The method of processing a wafer according to claim **1**, wherein,

in the modified layer forming step, the laser beam is applied a plurality of times to the first wafer with a height position of a focal point of the laser beam changed every time in a thickness direction of the first wafer, such that modified layers are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer.

3. The method of processing a wafer according to claim **1**, wherein,

in the modified layer forming step, a laser beam having a plurality of focal points apart from one another in a thickness direction of the first wafer is applied to the first wafer such that modified layers are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer.

4. A method of processing a wafer, comprising:

a plasma activation processing step of performing plasma processing on at least either one surface of a first wafer or one surface of a second wafer and thus activating the at least one surface that has been subjected to the plasma processing, to thereby join the first wafer and the second wafer;

a bonded wafer forming step of, after performing the plasma activation processing step, forming a bonded wafer by provisionally joining the one surface of the first wafer and the one surface of the second wafer;

a modified layer forming step of, after performing the bonded wafer forming step, forming modified layers in an annular pattern inside the first wafer and also forming cracks in such a manner as to spread from the modified layers and appear on the one surface of the first wafer, by applying a laser beam of a wavelength having transmissivity for the first wafer, in the annular pattern to the first wafer along a position on a side inner by a predetermined distance than an outer peripheral edge of the first wafer;

an anneal processing step of, after performing the modified layer forming step, performing anneal processing on the bonded wafer to increase joint strength between the first wafer and the second wafer;

an outer peripheral region removal step of, after performing the anneal processing step, removing an outer peripheral region of the first wafer, the outer peripheral region being on a side of the outer peripheral edge relative to the position where the modified layers have been formed in the annular pattern, by applying an external force to the outer peripheral region; and

a grinding step of, after performing the outer peripheral region removal step, grinding the first wafer of the bonded wafer from another surface of the first wafer to thin the first wafer to a predetermined finish thickness.

5. The method of processing a wafer according to claim **4**, wherein,

in the modified layer forming step, the laser beam is applied a plurality of times to the first wafer with a height position of a focal point of the laser beam changed every time in a thickness direction of the first wafer, such that modified layers are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer.

6. The method of processing a wafer according to claim **4**, wherein,

in the modified layer forming step, a laser beam having a plurality of focal points apart from one another in a thickness direction of the first wafer is applied to the first wafer such that modified layers are formed in a like plurality of annular patterns overlapping in the thickness direction of the first wafer.

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