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SUBSTRATE PROCESSING METHOD, SUBSTRATE PROCESSING APPARATUS AND SUBSTRATE PROCESSING SYSTEM

Abstract

A substrate processing method of transcribing, in a combined substrate in which a first substrate and a second substrate are bonded to each other, a device layer formed on a surface of the second substrate to the first substrate is provided. A laser beam is radiated in a pulse shape from a rear surface side of the second substrate to a laser absorption layer formed between the second substrate and the device layer.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This Application is a continuation application of U.S. patent application Ser. No. 17/788,776, which is a U.S. national phase application under 35 U.S.C. § 371 of PCT Application No. PCT/JP2020/045884 filed on Dec. 9, 2020, which claims the benefit of Japanese Patent Application No. 2019-236190 filed on Dec. 26, 2019 and Japanese Patent Application No. 2020-011824 filed on Jan. 28, 2020, the entire disclosures of which are incorporated herein by reference.

TECHNICAL FIELD
[0002] The various aspects and exemplary embodiments described herein pertain generally to a substrate processing method and a substrate processing apparatus.
BACKGROUND
[0003] Patent Document 1 discloses a method of manufacturing a semiconductor device. The method of manufacturing the semiconductor device includes a heating process of radiating a CO.sub.2 laser from a rear surface of a semiconductor substrate to locally heat a separation oxide film, and a transcription process of causing separation in the separation oxide film and/or at the interface between the separation oxide film and the semiconductor substrate to transcribe a semiconductor device to a transcription destination substrate.
PRIOR ART DOCUMENT
[0004] Patent Document 1: Japanese Patent Laid-open Publication No. 2007-220749
DISCLOSURE OF THE INVENTION
Means For Solving the Problems
[0005] In one exemplary embodiment, there is provided a substrate processing method of transcribing, in a combined substrate in which a first substrate and a second substrate are bonded to each other, a device layer formed on a surface of the second substrate to the first substrate. A laser beam is radiated in a pulse shape from a rear surface side of the second substrate to a laser absorption layer formed between the second substrate and the device layer.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0006] FIG. **1** is an explanatory diagram comparing a power of a laser beam when a pulse wave and a continuous wave are used.
[0007] FIG. **2** is a side view schematically illustrating a configuration of a combined wafer to be processed in a wafer processing system.
[0008] FIG. **3** is a plan view schematically illustrating a configuration of the wafer processing system.
[0009] FIG. **4** is a side view schematically illustrating a configuration of a laser radiation device according to the present exemplary embodiment.
[0010] FIG. **5** is a plan view schematically illustrating the configuration of the laser radiation device according to the present exemplary embodiment.
[0011] FIG. **6** is an explanatory diagram illustrating that the laser beam is radiated to a laser absorption layer according to the present exemplary embodiment.
[0012] FIG. **7** is an explanatory diagram illustrating that the laser beam is radiated to the laser

absorption layer according to the present exemplary embodiment.
[0013] FIG. **8** is an explanatory diagram illustrating that a laser beam is radiated to a laser absorption layer according to a modification example of the present exemplary embodiment.
[0014] FIG. **9**A and FIG. **9**B are explanatory diagrams illustrating that a second wafer is separated from the laser absorption layer.
[0015] FIG. **10** is an explanatory diagram schematically illustrating a configuration of a laser radiation unit according to another exemplary embodiment.
[0016] FIG. **11** is an explanatory diagram illustrating that a frequency of a laser beam is changed by an acousto-optic modulator according to another exemplary embodiment.
[0017] FIG. **12**A and FIG. **12**B are explanatory diagrams illustrating that the frequency of the laser beam is changed by the acousto-optic modulator according to another exemplary embodiment.
[0018] FIG. **13** is an explanatory diagram schematically illustrating a configuration of the laser radiation unit according to another exemplary embodiment.
[0019] FIG. **14** is an explanatory diagram schematically illustrating a configuration of the laser radiation unit according to another exemplary embodiment.
[0020] FIG. **15** is a side view schematically illustrating a configuration of a laser radiation device according to another exemplary embodiment.
[0021] FIG. **16** is a plan view schematically illustrating the configuration of the laser radiation device according to another exemplary embodiment.
[0022] FIG. **17** is an explanatory diagram illustrating that a laser beam is radiated to a laser absorption layer according to another exemplary embodiment.
[0023] FIG. **18** is an explanatory diagram illustrating that a laser beam is radiated to the laser absorption layer according to another exemplary embodiment.
[0024] FIG. **19** is an explanatory diagram illustrating that a laser beam is radiated to the laser absorption layer according to another exemplary embodiment.
[0025] FIG. **20** is a side view schematically illustrating a configuration of a laser radiation device according to another exemplary embodiment.
[0026] FIG. **21** is a side view schematically illustrating a configuration of a guide unit.
[0027] FIG. **22** is a side view schematically illustrating a configuration of a holding member.
[0028] FIG. **23** is a plan view schematically illustrating the configuration of the guide unit and the holding member.
[0029] FIG. **24**A and FIG. **24**B are explanatory diagrams illustrating that a device layer formed on a surface of a second wafer is transcribed to a first wafer according to another exemplary embodiment.
[0030] FIG. **25**A to FIG. **25**E are explanatory diagrams illustrating that the device layer formed on the surface of the second wafer is transferred to the first wafer according to another exemplary embodiment.
[0031] FIG. **26**A to FIG. **26**E are explanatory diagrams illustrating that the device layer formed on the surface of the second wafer is transferred to the first wafer according to another exemplary embodiment.
[0032] FIG. **27**A to FIG. **27**E are explanatory diagrams illustrating that the device layer formed on the surface of the second wafer is transferred to the first wafer according to another exemplary embodiment.
[0033] FIG. **28**A to FIG. **28**D are explanatory diagrams illustrating that the device layer formed on the surface of the second wafer is transferred to the first wafer according to another exemplary embodiment.
[0034] FIG. **29** is a side view schematically illustrating a configuration of a combined wafer according to another exemplary embodiment.

DETAILED DESCRIPTION

[0035] Recently, in a manufacturing process of LEDs, a so-called laser lift-off processing is performed in which a GaN (gallium nitride)-based compound crystal layer (material layer) is separated from a sapphire substrate using a laser beam. The reason for performing the laser lift-off processing is as follows. Since the sapphire substrate has transmittance to a short wavelength laser beam (for example, UV light), a short wavelength laser beam having a high absorptivity for an absorption layer can be used. Therefore, a wide choice of laser beams can be allowed.

[0036] Meanwhile, in a manufacturing process of semiconductor devices, a device layer formed on a surface of one substrate (silicon substrate such as semiconductor) is transcribed to another substrate. In general, a silicon substrate has transmittance to a laser beam in the NIR (near infrared) range, and an absorption layer also has transmittance to the laser beam in the NIR range. Therefore, the device layer can be damaged. Accordingly, in order to perform the laser lift-off processing in the manufacturing process of semiconductor devices, a laser beam in the FIR (far infrared) range is used.

[0037] In general, for example, a CO.sub.2 laser may be used as the laser beam having the FIR wavelength. In the method described above in Patent Document 1, radiation of the CO.sub.2 laser to the separation oxide film causes the separation at the interface between the separation oxide film and the substrate.

[0038] Here, as a result of intensive examination by the inventors, it is found that the separation may not occur simply by radiating the CO.sub.2 laser. That is, it is found that the separation occurs not depending on the energy amount of the CO.sub.2 laser but depending on the peak power (maximum intensity of the laser beam). For example, as shown in FIG. **1**, when the CO.sub.2 laser is continuously oscillated (when a continuous wave is used), it is difficult to increase the peak power, and, thus, the separation may not occur. When the CO.sub.2 laser is oscillated in a pulse shape (when a pulse wave is used), it is possible to increase the peak power, and, thus, the separation may occur. In the present disclosure, the laser beam that oscillates the CO.sub.2 laser in the pulse shape is a so-called pulsed laser, and its power varies repeatedly between 0 (zero) and a maximum value.

[0039] Further, when the CO.sub.2 laser is continuously oscillated, the laser lift-off may not be stably performed due to a large thermal influence. Thus, the device layer may be damaged by heat. Therefore, from this point of view, it is preferable to radiate the CO.sub.2 laser in the pulse shape.

[0040] As described above, in order to separate the separation oxide film (device layer) from the substrate, it is necessary to irradiate the separation oxide film with the CO.sub.2 laser in the pulse shape. However, according to the method of Patent Document 1, the pulsed laser is not considered at all and there is no suggestion thereof. Therefore, the conventional method of transcribing the device layer needs to be improved.

[0041] According to the present disclosure, in a combined substrate in which a first substrate and a second substrate are bonded to each other, a device layer formed on a surface of the second substrate is appropriately transcribed to the first substrate. Hereinafter, a wafer processing system including a laser radiation device as a substrate processing apparatus and a wafer processing method as a substrate processing method according to the present exemplary embodiment will be described with reference to the drawings. Further, in the present specification and the drawings, substantially the same functional components will be denoted by the same reference numerals and redundant descriptions thereof will be omitted.

[0042] As will be described below, a wafer processing system **1** according to the present exemplary embodiment performs a processing onto a combined wafer T as a combined substrate in which a first wafer W**1** as a first substrate and a second wafer W**2** as a second substrate are bonded to each other, as shown in FIG. **2**. Hereinafter, a surface of the first wafer W**1** to be bonded to the second wafer W**2** will be referred to as a front surface W**1***a* and a surface opposite to the front surface W**1***a* will be referred to as a rear surface W**1***b*. Likewise, a surface of the second wafer W**2** to be bonded to the first wafer W**1** will be referred to as a front surface W**2***a* and a surface opposite to the front surface W**2***a* will be referred to as a rear surface W**2***b*.

[0043] The first wafer W**1** is a semiconductor wafer such as a silicon substrate. A device layer D**1** and a front surface film F**1** are stacked on the front surface W**1***a* of the first wafer W**1** in this order from the front surface W**1***a*. The device layer D**1** includes a plurality of devices. Examples of the front surface film F**1** may include an oxide film (SiO.sub.2 film, TEOS film), an SiC film, an SiCN film or an adhesive. The device layer D**1** and the front surface film F**1** may not be formed on the front surface W**1***a*.
[0044] The second wafer W**2** is also a semiconductor wafer such as a silicon substrate. A laser absorption layer P, a device layer D**2** and a front surface film F**2** are stacked on the front surface W**2***a* of the second wafer W**2** in this order from the front surface W**2***a*. The laser absorption layer P is configured to absorb a laser beam radiated from a laser radiation unit **110**, as will be described later. For example, an oxide film (SiO.sub.2 film) is used as the laser absorption layer P. However, the laser absorption layer P is not particularly limited as long as it absorbs the laser beam. The device layer D**2** and the front surface film F**2** are the same as the device layer D**1** and the front surface film F**1**, respectively, of the first wafer W**1**. Further, the front surface film F**1** of the first wafer W**1** and the front surface film F**2** of the second wafer W**2** are bonded to each other. The position of the laser absorption layer P is not limited to the above-described exemplary embodiment. For example, the laser absorption layer P may be formed between the device layer D**2** and the front surface film F**2**. The device layer D**2** and the front surface film F**2** may not be formed on the front surface W**2***a*. In this case, the laser absorption layer P is formed on the first wafer W**1** and the device layer D**1** of the first wafer W**1** is transcribed to the second wafer W**2**.
[0045] As shown in FIG. **3**, the wafer processing system **1** includes a carry-in/out block **10**, a transfer block **20** and a processing block **30** which are connected as one body. The carry-in/out block **10** and the processing block **30** are provided around the transfer block **20**. Specifically, the carry-in/out block **10** is provided on a negative Y-axis direction side of the transfer block **20**. A laser radiation device **31** of the processing block **30** is provided on a negative X-axis direction side of the transfer block **20** and a cleaning device **32** to be described later is provided on a positive X-axis direction side of the transfer block **20**.
[0046] Cassettes Ct, Cw**1** and Cw**2** configured to accommodate a plurality of combined wafers T, a plurality of first wafers W**1** and a plurality of second wafers W**2**, respectively, are carried in/out between the carry-in/out block **10** and, for example, the outside. A cassette placing table **11** is provided in the carry-in/out block **10**. In the illustrated example, a plurality of, for example, three cassettes Ct, Cw**1** and Cw**2** can be placed in a row in an X-axis direction on the cassette placing table **11**. The number of cassettes Ct, Cw**1** and Cw**2** placed on the cassette placing table **11** is not limited to the present exemplary embodiment, but can be arbitrarily determined.
[0047] The transfer block **20** is provided with a wafer transfer device **22** which is movable along a transfer path **21** elongated in the X-axis direction. The wafer transfer device **22** has, for example, two transfer arms **23** and **23** which hold and transfer the combined wafer T, the first wafer W**1** and the second wafer W**2**. Each transfer arm **23** is movable in a horizontal direction, in a vertical direction, around a horizontal axis and around a vertical axis. The configuration of the transfer arm **23** is not limited to the present exemplary embodiment, but can be arbitrarily determined. Also, the wafer transfer device **22** is configured to transfer the combined wafer T, the first wafer W**1** and the second wafer W**2** to the cassettes Ct, Cw**1** and Cw**2** on the cassette placing table **11**, the laser radiation device **31** and the cleaning device **32**.
[0048] The processing block **30** is equipped with the laser radiation device **31** and the cleaning device **32**. The laser radiation device **31** radiates a laser beam to the laser absorption layer P of the second wafer W**2**. The configuration of the laser radiation device **31** will be described later.
[0049] The cleaning device **32** cleans a front surface of the laser absorption layer P formed on the front surface W**1***a* of the first wafer W**1** separated by the laser radiation device **31**. For example, the cleaning device **32** scrub-cleans the front surface by bringing a brush into contact with the front surface of the laser absorption layer P. A pressurized cleaning solution may be used to clean the

front surface. Also, the cleaning device **32** may be configured to clean the rear surface W**1***b* as well as the front surface W**1***a* of the first wafer W**1**.

[0050] The above-described wafer processing system **1** is provided with a control device **40** as a controller. The control device **40** is, for example, a computer, and is provided with a program storage (not shown). The program storage stores a program that controls a processing of the combined wafer T in the wafer processing system **1**. Also, the program storage stores a program for controlling operations of a driving unit such as the above-described processing devices and transfer devices to implement a wafer processing, which will be described below, in the wafer processing system **1**. Further, the program is recorded in a computer-readable recording medium H and may be installed on the control device **40** from the recording medium H.

[0051] Hereinafter, the laser radiation device **31** will be described.

[0052] As shown in FIG. **4** and FIG. **5**, the laser radiation device **31** includes a chuck **100** as a holder configured to hold the combined wafer T on an upper surface thereof. The chuck **100** is configured to attract and hold the entire rear surface W**1***b* of the first wafer W**1**. The chuck **100** may attract and hold a part of the rear surface W**1***b*. The chuck **100** is provided with an elevating pin (not shown) configured to support and elevate the combined wafer T from below. The elevating pin is inserted into a through-hole (not shown) formed through the chuck **100**, and is configured to be movable up and down.

[0053] The chuck **100** is supported on a slider table **102** via an air bearing **101** therebetween. A rotation mechanism **103** is provided at a bottom surface of the slider table **102**. The rotation mechanism **103** incorporates therein, for example, a motor as a driving source. The chuck **100** is configured to be rotatable around a θ axis (vertical axis) by the rotation mechanism **103** via the air bearing **101** therebetween. The slider table **102** is configured to be movable by a movement mechanism **104**, which is provided at the bottom surface thereof, along a rail **105** which is provided on a base **106** and elongated in a Y-axis direction. Further, although not particularly limited, a driving source of the movement mechanism **104** may be, for example, a linear motor.

[0054] The laser radiation unit **110** is provided above the chuck **100**. The laser radiation unit **110** includes a laser head **111**, an optical system **112** and a lens **113**. The laser head **111** is configured to oscillate a laser beam in a pulse shape. The optical system **112** controls intensity and a position of the laser beam, or adjusts the output by attenuating the laser beam. The lens **113** is a cylindrical member and is configured to radiate the laser beam to the combined wafer T held by the chuck **100**. In the present exemplary embodiment, the laser beam is a CO.sub.2 laser beam, and the laser beam output from the laser radiation unit **110** is transmitted through the second wafer W**2** to be radiated to the laser absorption layer P. Also, a wavelength of the CO.sub.2 laser beam is, for example, 8.9 μm to 11 μm. Further, the lens **113** is configured to be movable up and down by an elevating mechanism (not shown).

[0055] Further, a transfer pad **120** as a transfer unit is provided above the chuck **100**. The transfer pad **120** is configured to be movable up and down by an elevating mechanism (not shown). Furthermore, the transfer pad **120** has an adsorption surface for the second wafer W**2**. The transfer pad **120** transfers the second wafer W**2** between the chuck **100** and the transfer arm **23**. Specifically, after the chuck **100** is moved to a lower side of the transfer pad **120** (delivery position with the transfer arm **23**), the transfer pad **120** attracts and holds the rear surface W**2***b* of the second wafer W**2** to separate the second wafer W**2** from first wafer W**1**. Subsequently, the separated second wafer W**2** is transferred from the transfer pad **120** to the transfer arm **23** to be carried out of the laser radiation device **31**. The transfer pad **120** may also be configured to invert front and rear surfaces of a wafer by an inverting mechanism (not shown).

[0056] In the laser radiation device **31** shown in FIG. **5**, the transfer arm **23** accesses the transfer pad **120** from the positive X-axis direction side. However, the transfer arm **23** may access the transfer pad **120** from the negative Y-axis direction side by rotating the laser radiation device **31** shown in FIG. **5** 90 degrees counterclockwise.

[0057] When the combined wafer T is carried into the laser radiation device **31**, the combined wafer T is delivered from the transfer arm **23** to the elevating pin to be placed on the chuck **100** by lowering the elevating pin. Further, when the separated second wafer W**2** is carried out of the laser radiation device **31**, the combined wafer T placed on the chuck **100** is raised by the elevating pin to be delivered from the elevating pin to the transfer arm **23**.
[0058] Hereinafter, the wafer processing performed in the wafer processing system **1** configured as described above will be described. In the present exemplary embodiment, the first wafer W**1** and the second wafer W**2** are bonded to each other in an external bonding device (not shown) of the wafer processing system **1** to form the combined wafer T in advance.
[0059] First, the cassette Ct accommodating therein a plurality of combined wafers T is placed on the cassette placing table **11** of the carry-in/out block **10**.
[0060] Then, a combined wafer T in the cassette Ct is taken out by the wafer transfer device **22** and transferred to the laser radiation device **31**. In the laser radiation device **31**, the combined wafer T is transferred from the transfer arm **23** to the elevating pin to be attracted and held by the chuck **100**. Subsequently, the movement mechanism **104** moves the chuck **100** to a processing position. This processing position is a position where the laser beam can be radiated from the laser radiation unit **110** to the combined wafer T (laser absorption layer P).
[0061] Then, as shown in FIG. **6** and FIG. **7**, a laser beam L (CO.sub.2 laser beam) is radiated in a pulse shape from the laser radiation unit **110** to the laser absorption layer P, more specifically, an interface between the laser absorption layer P and the second wafer W**2**. Herein, the laser beam L is transmitted through the second wafer W**2** from the rear surface W**2***b* of the second wafer W**2** to be absorbed by the laser absorption layer P. Thereafter, the laser beam L causes separation at the interface between the laser absorption layer P and the second wafer W**2**. Almost all of the laser beam L is absorbed by the laser absorption layer P and does not reach the device layer D**2**. Therefore, it is possible to suppress damage to the device layer D**2**.
[0062] When the laser absorption layer P is irradiated with the laser beam L, the rotation mechanism **103** rotates the chuck **100** (combined wafer T) and the movement mechanism **104** moves the chuck **100** in the Y-axis direction. Then, the laser beam L is radiated to the laser absorption layer P from an outer side to an inner side thereof in a diametrical direction. As a result, the laser beam L is radiated in a spiral shape from the outer side to the inner side. Further, the black arrows shown in FIG. **7** indicate a rotation direction of the chuck **100**.
[0063] A radiation start position of the laser beam L is preferably between an outer edge Ea of the second wafer W**2** and a bonding edge Eb between the first wafer W**1** and the second wafer W**2** in the combined wafer T. In this case, for example, even if a center of the first wafer W**1** is misaligned and eccentric with a center of the second wafer W**2** in the combined wafer T, an eccentric amount is absorbed and the laser beam L can be appropriately radiated to the laser absorption layer P.
[0064] As shown in FIG. **8**, the laser beam L may be annularly radiated in a concentric circular shape to the laser absorption layer P. However, in this case, since the rotation of the chuck **100** and the movement of the chuck **100** in the Y-axis direction are alternately performed, it is preferable to radiate the laser beam L in the spiral shape as described above so as to shorten the radiation time and improve the throughput.
[0065] Further, the laser beam L may be radiated to the laser absorption layer P from the inner side to the outer side in the diametrical direction. However, in this case, since the inner side of the laser absorption layer P is separated first, a stress caused by the separation may be directed to the outer side in the diametrical direction, and a portion on the outer side without being irradiated with the laser beam L may also be separated. Meanwhile, if the laser beam Lis radiated from the outer side to the inner side in the diametrical direction as described above, the stress caused by the separation can be released to the outside. Therefore, it is possible to control the separation more easily. Further, by appropriately controlling the separation, it is possible to suppress the roughness of the separation surface.

[0066] Further, in the present exemplary embodiment, the chuck **100** is rotated while the laser beam L is radiated to the laser absorption layer P. Alternatively, the lens **113** may be moved to be rotated relative to the chuck **100**. Further, although the chuck **100** is moved in the Y-axis direction, the lens **113** may be moved in the Y-axis direction.

[0067] In this way, the laser radiation device **31** radiates the laser beam L to the laser absorption layer P. Since the laser beam L is radiated in the pulsed shape, the peak power of the laser beam L can be increased. Therefore, as described above with reference to FIG. **1**, the separation can occur at the interface between the laser absorption layer P and the second wafer W**2**. Thus, the second wafer W**2** can be appropriately separated from the laser absorption layer P.

[0068] Then, the chuck **100** is moved to the delivery position by the movement mechanism **104**. Thereafter, as shown in FIG. **9**A, the transfer pad **120** attracts and holds the rear surface W**2***b* of the second wafer W**2**. Then, as shown in FIG. **9**B, in a state where the transfer pad **120** attracts and holds the second wafer W**2**, the transfer pad **120** is raised to separate the second wafer W**2** from the laser absorption layer P. In this case, as described above, the separation occurs at the interface between the laser absorption layer P and the second wafer W**2** due to the radiation of the laser beam L. Thus, the second wafer W**2** can be separated from the laser absorption layer P without applying a large load.

[0069] The separated second wafer W**2** is delivered from the transfer pad **120** to the transfer arm **23** of the wafer transfer device **22** and transferred to the cassette Cw**2** on the cassette placing table **11**. Also, the second wafer W**2** carried out of the laser radiation device **31** may be transferred to the cleaning device **32** before being transferred to the cassette Cw**2**, and the front surface W**2***a*, which is the separation surface, of the second wafer W**2** may be cleaned. In this case, the transfer pad **120** may invert the front and rear surfaces of the second wafer W**2** and then transfer the second wafer W**2** to the transfer arm **23**.

[0070] The first wafer W**1** held by the chuck **100** is raised from the chuck **100** by the elevating pin, delivered to the transfer arm **23** and transferred to the cleaning device **32**. In the cleaning device **32**, a front surface, which is the separation surface, of the laser absorption layer P is scrub-cleaned. Also, in the cleaning device **32**, the rear surface W**1***b* of the first wafer W**1** may be cleaned together with the front surface of the laser absorption layer P. Further, the cleaning device **32** may be provided with separate cleaning units configured to respectively clean the front surface of the laser absorption layer P and the rear surface W**1***b* of the first wafer W**1**.

[0071] Thereafter, the first wafer W**1**, which has been subjected to all the processings, is transferred to the cassette Cw**1** on the cassette placing table **11** by the wafer transfer device **22**. In this way, a series of processes of the wafer processing in the wafer processing system **1** are completed.

[0072] According to the above-described exemplary embodiment, in the laser radiation device **31**, the laser beam L is radiated in the pulse shape to the laser absorption layer P. Thus, the peak power of the laser beam L can be increased. As a result, the separation can occur at the interface between the laser absorption layer P and the second wafer W**2**. Further, when the laser beam L is radiated in the pulse shape, the laser lift-off can be stably performed due to the smaller thermal influence than when the continuous wave is used. Therefore, the second wafer W**2** can be appropriately separated from the laser absorption layer P and the device layer D**2** can be transcribed to the first wafer W**1**.

[0073] Herein, an interval of radiating the laser beam L, i.e., a pulse interval, is preferably set to be uniform to achieve uniform separation between the first wafer W**1** and the second wafer W**2** in the surface of the wafer. However, if the chuck **100** (combined wafer T) is rotated, a rotation speed of the chuck **100** increases as the laser beam L moves from the outer side to the inner side in the diametrical direction to make the pulse interval uniform. In this case, when the rotation speed of the chuck **100** reaches an upper limit, an interval between the laser beams L may decrease as the radiation position of the laser beam L moves to the inner side in the diametrical direction. Thus, the laser beams L may overlap with each other at a central portion. Therefore, the interval of radiating the laser beam L needs to be adjusted. For example, there are two methods as follows.

[0074] The first method is to control the rotation speed of the chuck **100**. That is, when the radiation position of the laser beam L is on the outer side in the diametrical direction of the laser absorption layer P, the rotation speed is decreased, and when the radiation position of the laser beam L is on the inner side, the rotation speed is increased. The adjustment of the rotation speed is performed depending on the frequency of the laser beam L. In this case, the interval of radiating the laser beam L can be made uniform by rotating the chuck **100** at a constant rotation speed.
[0075] The second method is to control the frequency of the laser beam L. That is, when the radiation position of the laser beam L is on the outer side in the diametrical direction of the laser absorption layer P, the frequency is increased, and when the radiation position of the laser beam L is on the inner side, the frequency is decreased. The adjustment of the frequency is performed depending on the rotation speed of the chuck **100**. Even in this case, the interval of radiating the laser beam L can be made uniform by rotating the chuck **100** at a constant rotation speed.
[0076] Also, in order to shorten the processing time (tact) of the laser radiation and improve the throughput, it is preferable to maintain the rotation speed of the chuck **100** by using the laser beam L having a high frequency in the first method.
[0077] Alternatively, the first method and the second method may be performed together. In this case, the frequency of the laser beam L is increased while decreasing the rotation speed of the chuck **100** on the outer side in the diametrical direction. Meanwhile, the frequency of the laser beam L is decreased while increasing the rotation speed of the chuck **100** on the inner side in the diametrical direction.
[0078] Here, when controlling the frequency of the laser beam L in the second method, for example, when controlling the frequency of the laser beam L in a laser oscillator of the laser head **111**, it is necessary to adjust parameters in consideration of the output or the pulse waveform of the laser beam L. For example, if the energy of the laser beam L required for the separation on the outer side in the diametrical direction of the laser absorption layer P is identical to the energy of the laser beam L required for the separation on the inner side in the diametrical direction of the laser absorption layer P, it is necessary to increase the output when increasing the frequency of the laser beam L on the outer side and decrease the output when decreasing the frequency of the laser beam L on the inner side. Further, when the frequency of the laser beam L is changed in the laser oscillator, the pulse waveform of the laser beam L is also changed, which requires a complicated adjustment in consideration of the output or the pulse waveform of the laser beam L. Therefore, it is difficult to control the process of laser processing.
[0079] Therefore, in the present exemplary embodiment, the frequency of the laser beam L is controlled by using an acousto-optic modulator as an optical element. As described above, the laser radiation unit **110** includes the laser head **111**, the optical system **112** and the lens **113**.
[0080] As shown in FIG. **10**, the laser head **111** has a laser oscillator **130** configured to oscillate the laser beam in the pulse shape. The frequency of the laser beam oscillated from the laser oscillator **130** is the highest frequency that can be allowed to be controlled by an acousto-optic modulator (AOM) **131** to be described later. Also, the laser head **111** may have other devices, for example, an amplifier, in addition to the laser oscillator **130**.
[0081] The optical system **112** includes the acousto-optic modulator (AOM) **131** configured to divert the laser beam from the laser oscillator **130** in a different direction and an attenuator **132** configured to attenuate the laser beam from the laser oscillator **130** and adjust the output of the laser beam. The AOM **131** and the attenuator **132** are provided in this order from the laser oscillator **130**.
[0082] The AOM **131** is an optical modulator configured to electrically control the intensity and the position of the laser beam at a high speed. As shown in FIG. **11**, when a laser beam L**1** from the laser oscillator **130** is incident, the AOM **131** applies a voltage to change the refractive index of the laser beam L**1** and thus diverts the laser beam L**1** in a different direction. Specifically, a changed angle of the laser beam L**1** can be controlled by adjusting the voltage. In the present exemplary

embodiment, for example, the laser beam L**1** is diverted in two different directions, and a laser beam L**2** in one direction is radiated to the laser absorption layer P and a laser beam L**3** in the other direction is not radiated to the laser absorption layer P. By controlling the diversion of the laser beams L**2** and L**3**, it is possible to adjust the frequency of the laser beam L**2** radiated to the laser absorption layer P.

[0083] In this case, the frequency of the laser beam L**2** radiated to the laser absorption layer P can be adjusted by thinning out the pulse of the laser beam L**1** with the AOM **131**. For example, if a diversion ratio of the laser beam L**2** and the laser beam L**3** to the laser beam L**1** is set to 100:0 at a certain timing, the laser beam L**1** becomes the laser beam L**2** as it is and is radiated to the laser absorption layer P. If the diversion ratio of the laser beam L**2** and the laser beam L**3** to the laser beam L**1** is set to 0:100 at another timing, the laser beam L**2** has a value of 0 (zero) and the laser beam L**2** is not radiated to the laser absorption layer P. In this case, the frequency of the laser beam L**2** diverted by the AOM **131** shown in FIG. **12**B can be adjusted with respect to the frequency of the laser beam L**1** from the laser oscillator **130** shown in FIG. **12**A. Further, as described above, since the frequency of the laser beam L**1** is the highest frequency that can be allowed to be controlled by the AOM **131**, the frequency of the laser beam L**2** can be adjusted as required. The horizontal axis of FIG. **12**A and FIG. **12**B shows time, and the vertical axis shows the intensity of the laser beam L**2**. That is, the density of the graph in FIG. **12**A and FIG. **12**B indicates the frequency of the laser beam L**2**.

[0084] Moreover, in this case, since the frequency of the laser beam L**1** oscillated from the laser oscillator **130** is not changed, the pulse waveform of the laser beam L**1** is not changed. Thus, the pulse waveform of the laser beam L**2** can be made identical to the pulse waveform of the laser beam L**1**. Therefore, it is possible to easily adjust the frequency of the laser beam L**2** and it is not necessary to perform the conventional complicated adjustment as described above. Accordingly, it becomes easy to control the process of laser processing.

[0085] In the present exemplary embodiment, the AOM **131** is used as the optical element, but the present disclosure is not limited thereto. For example, an electro-optical modulator (EOM) may be used as the optical element. Further, an optical deflector such as an acousto-optic deflector (AOD) or an electro-optical deflector (EOD) may be used.

[0086] Hereinafter, a method of controlling the laser beam L**2** when the laser radiation unit **110** radiates the laser beam L**2** to the laser absorption layer P will be described. As described above, when a radiation position of the laser beam L**2** is on the outer side in the diametrical direction of the laser absorption layer P, the frequency is increased, and when the radiation position of the laser beam L**2** is on the inner side, the frequency is decreased.

[0087] Hereinafter, a specific example will be described. A numerical value in this specific example is an example, and the present disclosure is not limited thereto numerical value. For example, the energy required for the separation on each of the outer side and inner side in the diametrical direction of the laser absorption layer P is set to 400 μJ. A required frequency of the laser beam L**2** on the outer side in the diametrical direction of the laser absorption layer P is set to 100 kHz, and a required frequency of the laser beam on the inner side is set to 50 kHz. The frequency of the laser beam L**1** from the laser oscillator **130** is set to 100 kHz and the output thereof is set to 40 W.

[0088] In this case, the pulse of the laser beam L**1** from the laser oscillator **130** is not thinned out by the AOM **131** on the outer side in the diametrical direction of the laser absorption layer P. Then, the frequency of the laser beam L**2** radiated to the laser absorption layer P becomes 100 kHz, which is identical to the frequency of the laser beam L**1**. Further, the output of the laser beam L**2** becomes 40 W, which is identical to the output of the laser beam L**1**. Also, the energy of the laser beam L**2** becomes 400 μJ (=40 W/100 kHz). Thus, the separation can be appropriately performed.

[0089] Meanwhile, the pulse of the laser beam L**1** from the laser oscillator **130** is thinned out to half by the AOM **131** on the inner side in the diametrical direction of the laser absorption layer P.

Then, the frequency of the laser beam L**2** radiated to the laser absorption layer P becomes 50 kHz, which is half the frequency of the laser beam L**1**. Further, by thinning out the laser beam L**1**, the output of the laser beam L**2** becomes 20 W, which is half the output of the laser beam L**1**. Also, the energy of the laser beam L**2** becomes 400 μJ (=20 W/50 kHz). Thus, the separation can be appropriately performed.

[0090] As described above, the rotation speed of the chuck **100** is controlled to make the pulse interval uniform depending on the frequency and the radiation position of the laser beam L**2**. Then, at the central portion of the laser absorption layer P, the maximum rotation speed of the chuck **100** is maintained and the AOM **131** adjusts the frequency of the laser beam L**2** based on the maximum rotation speed. Accordingly, the laser processing can be performed while the high rotation speed of the chuck **100** and the high frequency of the laser beam L**2** are maintained. Thus, the laser processing can be implemented with the high throughput.

[0091] Moreover, in this case, since the frequency of the laser beam L**1** from the laser oscillator **130** is not changed, the pulse waveform of the laser beam L**1** is not changed. Thus, the pulse waveform of the laser beam L**2** can be made identical to the pulse waveform of the laser beam L**1**. Therefore, the frequency of the laser beam L**2** can be easily adjusted, which makes it possible to perform a continuous seamless process. As a result, it becomes easy to control the process of laser processing and it is possible to implement a stable process.

[0092] In the present exemplary embodiment, since the output of the laser beam L**1** from the laser oscillator **130** is 40 W, it is not necessary to adjust the output with respect to the energy of 400 μJ required for the separation. In this respect, for example, when the output of the laser beam L**1** is 50 W, the attenuator **132** may attenuate the output of the laser beam L**1** by 20% to adjust the output.

[0093] In the laser radiation unit **110** according to the above-described exemplary embodiment, the AOM **131** is provided on an upstream side of the attenuator **132** inside the optical system **112**, but the installation position is not limited thereto. For example, as shown in FIG. **13**, the AOM **131** may be provided on a downstream side of the attenuator **132** inside the optical system **112**. Alternatively, for example, as shown in FIG. **14**, the AOM **131** may be provided on a downstream side of the laser oscillator **130** inside the laser head **111**. Further, the AOM **131** may be provided at two or more of the above-described installation positions.

[0094] In the laser radiation unit **110**, after the AOM **131** adjusts the frequency and output of the laser beam L**2**, the attenuator **132** can finely adjust the output. Herein, the output of the laser beam L**1** oscillated from the laser oscillator **130** may become non-uniform depending on the individual difference of the laser oscillator **130**. The attenuator **132** can correct the non-uniformity in output. Further, when the output of the laser beam L**1** from the laser oscillator **130** is monitored over time, the attenuator **132** can be feedback-controlled to adjust the output. Also, from the viewpoint of finely adjusting the output of the laser beam L**2** by the attenuator **132**, the AOM **131** is preferably provided on the upstream side of the attenuator **132** as shown in FIG. **10**.

[0095] The attenuator **132** may be omitted from the laser radiation unit **110** according to the above-described exemplary embodiment. For example, the output of the laser beam L**2** may be adjusted by the AOM **131** instead of the attenuator **132**. For example, if the output of the laser beam L**1** is 50 W and the output of the laser beam L**2** required for separation is 40 W, the AOM **131** may adjust the diversion ratio of the laser beam L**2** and the laser beam L**3** to the laser beam L**1** to 80:20 to set the output of the laser beam L**2** to 40 W.

[0096] In the above-described exemplary embodiment, the laser absorption layer P is irradiated with the laser beam L in the spiral shape or the concentric circular shape, but the radiation pattern of the laser beam Lis not limited thereto. Further, the configuration of the device corresponding to such various radiation patterns is not limited to the laser radiation device **31** of the above-described exemplary embodiment. In the laser radiation device **31**, the chuck **100** is rotatable around the θ axis and movable in the uniaxial (Y-axis) direction, but may be moved in biaxial (X-axis and Y-axis) directions.

[0097] A laser radiation device **200** shown in FIG. **15** and FIG. **16** is a device configured to move the chuck **100** in biaxial (X-axis and Y-axis) directions. The laser radiation device **200** includes a chuck **210** as a holder configured to hold the combined wafer T on an upper surface thereof. The chuck **210** is configured to attract and hold the entire rear surface W**1***b* of the first wafer W**1**. The chuck **210** is provided with an elevating pin (not shown) configured to support and elevate the combined wafer T from below. The elevating pin is inserted into a through-hole (not shown) formed through the chuck **210**, and is configured to be movable up and down.
[0098] The chuck **210** is supported on a slider table **212** via an air bearing **211** therebetween. A rotation mechanism **213** is provided at a bottom surface of the slider table **212**. The rotation mechanism **213** incorporates therein, for example, a motor as a driving source. The chuck **210** is configured to be rotatable around the θ axis (vertical axis) by the rotation mechanism **213** via the air bearing **211** therebetween. The slider table **212** is configured to be movable by a movement mechanism **214**, which is provided at the bottom surface thereof, along a rail **215** which is provided on a movement stage **216** and elongated in the Y-axis direction. Further, although not particularly limited, a driving source of the movement mechanism **214** may be, for example, a linear motor.
[0099] The movement stage **216** is configured to be movable by a movement mechanism (not shown), which is provided at the bottom surface thereof, along a rail **217** which is provided on a base **218** and elongated in the X-axis direction. Further, although not particularly limited, a driving source of the movement mechanism may be, for example, a linear motor. With this configuration, the chuck **210** is rotatable around the θ axis and movable in the X-axis and Y-axis directions.
[0100] A laser radiation unit **220** is provided above the chuck **210**. The laser radiation unit **220** includes a laser head **221**, an optical system **222** and a lens **223**. The laser head **221** is configured to oscillate a laser beam L in a pulse shape. The optical system **222** controls intensity and a position of the laser beam L, or adjusts the output by attenuating the laser beam L. The lens **223** is a cylindrical member and is configured to radiate the laser beam L, e.g., a CO.sub.2 laser beam, to the combined wafer T held by the chuck **210**. Further, the lens **223** is configured to be movable up and down by an elevating mechanism (not shown).
[0101] For example, galvano is used for the laser head **221**. A plurality of galvano mirrors (not shown) is arranged inside the laser head **221**. Further, an f-θ lens is used for the lens **223**. With this configuration, the laser beam L input to the laser head **221** is reflected by the galvano mirrors, propagated to the lens **223** via the optical system **222**, transmitted through the second wafer W**2** and radiated to the laser absorption layer P. Furthermore, the laser absorption layer P may be scanned with the laser beam L by adjusting the angle of the galvano mirrors.
[0102] Also, a transfer pad **230** as a transfer unit is provided above the chuck **210**. The transfer pad **230** is configured to be movable up and down by an elevating mechanism (not shown). The transfer pad **230** has the same configuration as the transfer pad **120** of the above-described exemplary embodiment.
[0103] In the laser radiation device **200**, the combined wafer T is delivered from the transfer arm **23** to the elevating pin to be attracted and held by the chuck **210**. Subsequently, the movement mechanism **214** and the movement stage **216** move the chuck **210** to a processing position. This processing position is a position where the laser beam L can be radiated from the laser radiation unit **220** to the combined wafer T (laser absorption layer P).
[0104] Then, as shown in FIG. **17**, the laser beam L is radiated in a pulse shape from the laser radiation unit **220** to the laser absorption layer P. Herein, the laser beam L is transmitted through the second wafer W**2** from the rear surface W**2***b* of the second wafer W**2** to be absorbed by the laser absorption layer P.
[0105] When the laser absorption layer P is irradiated with the laser beam L, a predetermined scanning range A (square region in FIG. **17**) is scanned with the laser beam L. Then, the chuck **210** is moved in the X-axis direction in a state where the radiation of the laser beam L is stopped. In this way, the laser beam L is radiated in a row in the X-axis direction by repeatedly performing the

radiation and the scanning of the laser beam L and the movement of the chuck **210**. Thereafter, the chuck **210** is moved in the Y-axis direction, and then, the laser beam L is radiated in a row in the X-axis direction by repeatedly performing the radiation and the scanning of the laser beam L and the movement of the chuck **210** as described above. As a result, the laser beam L is radiated to the laser absorption layer P.

[0106] In the present exemplary embodiment, when the laser absorption layer P is irradiated with the laser beam L, the chuck **210** is moved in the X-axis direction and the Y-axis direction, but the lens **223** may be moved relative to the chuck **210**.

[0107] Then, the chuck **210** is moved to the delivery position by the movement mechanism **214** and the movement stage **216**. Thereafter, the transfer pad **230** attracts and holds the rear surface W**2***b* of the second wafer W**2**, and the transfer pad **230** is raised to separate the second wafer W**2** from the laser absorption layer P.

[0108] In the present exemplary embodiment as well, the same effects as obtained in the above-described exemplary embodiment can be achieved. That is, since the laser beam L is radiated in the pulse shape to the laser absorption layer P, the peak power of the laser beam L can be increased. As a result, the separation can occur at the interface between the laser absorption layer P and the second wafer W**2**. Moreover, since the scanning range A can be irradiated with the laser beam L of the same density, the laser beam L can be uniformly radiated to the laser absorption layer P.

[0109] In the present exemplary embodiment, there may be a plurality of laser radiation units **220**. In this case, the laser absorption layer P can be irradiated with a plurality of laser beams L. Also, the processing time can be shortened and the throughput can be further improved.

[0110] In the above-described exemplary embodiment, the radiation and the scanning of the laser beam L and the movement of the chuck **210** are repeatedly performed. However, as shown in FIG. **18**, the radiation and the scanning of the laser beam L may be performed in a row in the X-axis direction while moving the chuck **210**. After the laser beam L is radiated in a row in the X-axis direction, the chuck **210** is moved in the Y-axis direction and the laser beam L is radiated to the laser absorption layer P.

[0111] In the present exemplary embodiment as well, the same effects as obtained in the above-described exemplary embodiment can be achieved. That is, since the laser beam L is radiated in the pulse shape to the laser absorption layer P, the separation can occur at the interface between the laser absorption layer P and the second wafer W**2**. Moreover, since the radiation and the scanning of the laser beam L in a row in the X-axis direction are not stopped, the processing time of laser radiation can be shortened and the throughput can be further improved.

[0112] The radiation of the laser beam L in the spiral shape (or concentric circular shape) according to the above-described exemplary embodiment may be combined with the radiation and the scanning of the laser beam L.

[0113] If the chuck **210** (combined wafer T) is rotated, the rotation speed of the chuck **210** increases as the laser beam L moves from the outer side to the inner side in the diametrical direction to make the pulse interval uniform as described above. Therefore, in the above-described exemplary embodiment, at least the rotation speed of the chuck **210** or the frequency is controlled to adjust the interval of radiating the laser beam L.

[0114] In this regard, as shown in FIG. **19**, on an outer peripheral portion of the laser absorption layer P, the laser beam L is radiated in a spiral shape by moving the chuck **210** to move the radiation position of the laser beam L from the outer side to the inner side in the diametrical direction while rotating the chuck **210**. When the rotation speed of the chuck **210** reaches an upper limit, rotation of the chuck **210** is stopped at the central portion of the laser absorption layer P and the scanning range A is scanned while radiating the laser beam L. Although the scanning range A is illustrated as having a square shape, the shape of the scanning range A is not limited thereto. For example, the scanning range A may have a round shape.

[0115] As described above, since the radiation pattern of the laser beam L is changed between the outer peripheral portion and the central portion of the laser absorption layer P, the laser beams L may not overlap with each other and the interval of radiating the laser beam L, i.e., the pulse interval, may be made uniform. As a result, it is possible to achieve the uniform separation between the first wafer W**1** and the second wafer W**2** in the surface of the wafer.

[0116] When the radiation range of the laser beam L from the laser radiation unit **220** is wide, for example, when the radiation range is equal to or greater than the diameter of the laser absorption layer P, the laser beam L may be radiated to the entire surface of the laser absorption layer P at a time.

[0117] In the laser radiation device **31** of the above-described exemplary embodiment, as shown in FIG. **20**, a guide unit **240** and a holding member **250** may be provided on an upper surface of the chuck **100**.

[0118] As shown in FIG. **21**, the guide unit **240** is configured to guide the combined wafer T to the chuck **100**. The guide unit **240** has a vertical portion **241** extending vertically upwards from the chuck **100** and an inclined portion **242** provided so as to increase the diameter thereof upwards from the vertical portion **241**. An inner diameter of the vertical portion **241** is slightly greater than the diameter of the combined wafer T. The combined wafer T placed above the chuck **100** is centered by the inclined portion **242** and guided by the vertical portion **241** and then held by the chuck **100**.

[0119] As shown in FIG. **22** and FIG. **23**, the holding member **250** extends vertically upwards from the upper surface of the chuck **100** and holds a side surface of the second wafer W**2**. The holding member **250** is arranged at each of a plurality of, for example, three locations on concentric circles of the chuck **100**. The holding member **250** is configured to be movable forwards and backwards by a movement mechanism **251** so as to be in contact with or separated from the second wafer W**2**. Further, the holding member **250** is configured to be rotatable together with the chuck **100**. Since the holding member **250** holds the second wafer W**2**, it is possible to suppress misalignment and slipping-down of the second wafer W**2**. In the guide unit **240**, a notch **243** is formed at a position corresponding to the holding member **250**. Further, the holding member **250** is moved through the notch **243** so as not to interfere with the guide unit **240**.

[0120] Although both the guide unit **240** and the holding member **250** are provided in the present exemplary embodiment, only the guide unit **240** may be provided or only the holding member **250** may be provided. If only the guide unit **240** is provided, the vertical portion **241** can suppress the misalignment and the slipping-down of the second wafer W**2**. In particular, when a gap between the vertical portion **241** and the second wafer W**2** is within an allowable range of the misalignment, the guide unit **240** becomes useful. However, when both the guide unit **240** and the holding member **250** are provided, it is more effective in centering the combined wafer T and suppressing the misalignment and the slipping-down of the second wafer W**2**.

[0121] In this case, when the combined wafer T is held by the chuck **100** at the delivery position, the three holding members **250** retreat to positions where they are not in contact with the second wafer W**2**. Then, after the chuck **100** holding the combined wafer T is moved to the processing position, the three holding members **250** are moved to positions where they are in contact with the side surface of the second wafer W**2** to hold the second wafer W**2**.

[0122] When the guide unit **240** and the holding member **250** are not provided, if the laser beam L is radiated in the spiral shape from the outer side to the inner side in the diametrical direction of the laser absorption layer P, the separation may occur, and since the chuck **100** is rotated, a centrifugal force acts on the second wafer W**2** so that the second wafer W**2** is misaligned with the laser absorption layer P. Thus, the laser beam L may be radiated to a place other than the processing target position during the laser processing. Also, the separated second wafer W**2** may slip down. In this respect, in the present exemplary embodiment, the holding member **250** holds the second wafer W**2**, and, thus, it is possible to suppress the misalignment or the slipping-down of the second wafer W**2**.

[0123] Even when the chuck **100** is moved to the delivery position after the radiation of the laser beam L, the holding member **250** holds the second wafer W**2**. Herein, while the chuck **100** is moved, an inertial force acts on the second wafer W**2**, and, thus, the second wafer W**2** may be misaligned with the laser absorption layer P. In this case, when the rear surface W**2***b* of the second wafer W**2** is attracted and held subsequently by the transfer pad **120**, the transfer pad **120** cannot attract and hold an appropriate position. Therefore, in the present exemplary embodiment, even while the chuck **100** is moved, the holding member **250** holds the second wafer W**2** to suppress the misalignment of the second wafer W**2**.
[0124] A configuration of the holding member configured to hold the second wafer W**2** is not limited to the configuration of the holding member **250**. For example, the holding member may hold the second wafer W**2** from a side portion of the second wafer W**2** to sandwich the upper surface and the side surface of the second wafer W**2**. Further, the holding member may hold the second wafer W**2** in the middle of the laser processing. Furthermore, if the holding member is made of a material, e.g., silicon, that transmits the laser beam L, the holding member may hold the upper surface of the second wafer W**2**.
[0125] The wafer processing system **1** of the above-described exemplary embodiment includes the cleaning device **32**, but the wafer processing system **1** may further include an etching device (not shown). The etching device is configured to etch the front surface W**1***a* of the first wafer W**1**, specifically, the front surface of the laser absorption layer P after the separation. For example, after the front surface of the laser absorption layer P is scrub-cleaned by the cleaning device **32**, a chemical solution (etching solution) is supplied to the front surface of the laser absorption layer P to wet-etch the front surface. Further, the wafer processing system **1** may include either the cleaning device **32** or the etching device.
[0126] Further, the wafer processing system **1** of the above-described exemplary embodiment may include a CMP (chemical mechanical polishing) device (not shown). The CMP device is configured to perform a CMP processing to the front surface W**1***a* of the first wafer W**1**, specifically, the front surface of the laser absorption layer P after the separation. For example, after the front surface of the laser absorption layer P is scrub-cleaned by the cleaning device **32**, the CMP processing is performed on the front surface of the laser absorption layer P to flatten the front surface of the laser absorption layer P. The CMP device may be provided outside the wafer processing system **1**.
[0127] In the above-described exemplary embodiment, the laser beam L is radiated to the interface between the laser absorption layer P and the second wafer W**2** to separate the second wafer W**2** from the laser absorption layer P. However, for example, as shown in FIG. **24**A and FIG. **24**B, the laser absorption layer P may be separated so as to remain on the second wafer W**2**.
[0128] In this case, in the laser radiation device **31**, the laser beam L is radiated the a pulse shape from the laser radiation unit **110** to the interface between the laser absorption layer P and the device layer D**2** as shown in FIG. **24**A. Then, the laser beam L causes the separation at the interface between the laser absorption layer P and the device layer D**2**.
[0129] The adjustment of the absorption position of the laser beam L, i.e., adjustment of the separation position of the laser absorption layer P, is performed by controlling an energy density of the laser beam L required for the separation of the laser absorption layer P depending on the film type of the laser absorption layer P. For example, the energy density of the laser beam L can be adjusted by adjusting a focus numerical aperture (NA) of the laser radiation unit **110**, changing a focus position of the laser beam L, changing an original output of the laser beam L, and the like.
[0130] Then, in a state where the transfer pad **120** attracts and holds the rear surface W**2***b* of the second wafer W**2**, the transfer pad **120** is raised as shown in FIG. **24**B to separate the laser absorption layer P from the device layer D**2**.
[0131] In the present exemplary embodiment as well, the same effects as obtained in the above-described exemplary embodiment can be achieved. That is, since the laser beam L is radiated in the pulse shape to the laser absorption layer P, the peak power of the laser beam L can be increased. As

a result, the separation can occur at the interface between the laser absorption layer P and the device layer D**2**. Moreover, the laser absorption layer P remaining on the second wafer W**2** is an oxide film (SiO.sub.2 film). For example, in a subsequent semiconductor manufacturing process, the remaining laser absorption layer P can be used as an oxide film (insulating film) when a TSV (Through-Silicon Via) is formed in the second wafer W**2**.

[0132] Further, in the present exemplary embodiment, the front surface of the laser absorption layer P on the second wafer W**2** after the separation may be scrub-cleaned and may be further subjected to the CMP processing by the CMP device. In this case, the front surface of the laser absorption layer P can be flattened. Also, as described above, the laser absorption layer P can be appropriately used as the oxide film (insulating film) when the TSV is formed.

[0133] In the above-described exemplary embodiment, a case of processing the combined wafer T shown in FIG. **2** has been described, but the processing target is not limited thereto. Hereinafter, cases of processing different types of combined wafers T will be described with reference to FIG. **25**A to FIG. **28**D.

[0134] A case of processing the combined wafer T shown in FIG. **25**A to FIG. **25**E will be described. As shown in FIG. **25**A, a laser absorption layer P**1** formed between the second wafer W**2** and the device layer D**2** is formed inside the second wafer W**2**. The second wafer W**2** is, for example, an SOI substrate and the laser absorption layer P**1** is, for example, an oxide film (SiO.sub.2 film). That is, Si, which is the second wafer W**2**, an SiO.sub.2 film, which is the laser absorption layer P**1**, and Si, which is an Si film S, are sequentially stacked. As the laser absorption layer P**1**, a film other than the oxide film (SiO.sub.2 film), e.g., silicon germanium (SiGe) or germanium (Ge), may be used as long as it is separated at the interface with the Si film S.

[0135] Then, as shown in FIG. **25**B, the device layer D**2** and a front surface film F**2** are formed on a front surface of the laser absorption layer P**1**. The device layer D**2** and the front surface film F**2** are formed by a typical substrate process (FEOL) or interconnect process (BEOL).

[0136] Thereafter, as shown in FIG. **25**C, the first wafer W**1** and the second wafer W**2** are bonded to each other. The front surface film F**1** formed on the front surface W**1***a* of the first wafer W**1** is bonded to the front surface film F**2**.

[0137] Then, in the laser radiation device **31** of the wafer processing system **1**, the laser beam L is radiated in the pulse shape from the laser radiation unit **110** to the interface between the laser absorption layer P**1** and the Si film S as shown in FIG. **25**D. Thereafter, the laser beam L causes the separation at the interface between the laser absorption layer P**1** and the Si film S.

[0138] Subsequently, in a state where the transfer pad **120** attracts and holds the rear surface W**2***b* of the second wafer W**2**, the transfer pad **120** is raised as shown in FIG. **25**E to separate the laser absorption layer P**1** from the Si film S.

[0139] In the present exemplary embodiment as well, the separation position of the laser absorption layer P**1** may be adjusted by adjusting the absorption position of the laser beam L, i.e., the separation position of the laser absorption layer P**1**, as in the case shown in FIG. **24**A and FIG. **24**B, and the separation may occur at the interface between the second wafer W**2** and the laser absorption layer P**1**.

[0140] A case of processing the combined wafer T shown in FIG. **26**A to FIG. **26**E will be described. As shown in FIG. **26**A and FIG. **26**B, a laser absorption layer P**2** made of silicon germanium (SiGe) and the Si film S made of Si are formed between the second wafer W**2** and the device layer D**2** to be stacked in this order from the second wafer W**2**.

[0141] Then, as shown in FIG. **26**B, the device layer D**2** and the front surface film F**2** are formed on a front surface of the Si film S.

[0142] Thereafter, as shown in FIG. **26**C, the first wafer W**1** and the second wafer W**2** are bonded to each other. The device layer D**1** and the front surface film F**1** are formed on the front surface W**1***a* of the first wafer W**1**, and the front surface film F**1** is bonded to the front surface film F**2**.

[0143] Then, in the laser radiation device **31** of the wafer processing system **1**, the laser beam L is radiated in the pulse shape from the laser radiation unit **110** to the interface between the laser absorption layer P**2** and the Si film S as shown in FIG. **26**D. Thereafter, the laser beam L causes the separation at the interface between the laser absorption layer P**2** and the Si film S.

[0144] Subsequently, in a state where the transfer pad **120** attracts and holds the rear surface W**2***b* of the second wafer W**2**, the transfer pad **120** is raised as shown in FIG. **26**E to separate the laser absorption layer P**2** from the Si film S. In the present exemplary embodiment as well, the separation position of the laser absorption layer P**2** may be adjusted by adjusting the absorption position of the laser beam L, i.e., the separation position of the laser absorption layer P**2**, as in the case shown in FIG. **24**A and FIG. **24**B, and the separation may occur at the interface between the second wafer W**2** and the laser absorption layer P**2**.

[0145] A case of processing the combined wafer T shown in FIG. **27**A to FIG. **27**E will be described. As shown in FIG. **27**A and FIG. **27**B, a laser absorption layer P**3** made of an oxide film (SiO.sub.2 film), an SiGe film S**1** made of SiGe and an Si film S**2** made of Si are formed between the second wafer W**2** and the device layer D**2** to be stacked in this order from the second wafer W**2**.

[0146] Then, as shown in FIG. **27**B, the device layer D**2** and the front surface film F**2** are formed on a front surface of the Si film S**2** made of Si.

[0147] Thereafter, as shown in FIG. **27**C, the first wafer W**1** and the second wafer W**2** are bonded to each other. The device layer D**1** and the front surface film F**1** are formed on the front surface W**1***a* of the first wafer W**1**, and the front surface film F**1** is bonded to the front surface film F**2**.

[0148] Then, in the laser radiation device **31** of the wafer processing system **1**, the laser beam L is radiated in the pulse shape from the laser radiation unit **110** to the interface between the laser absorption layer P**3** and the second wafer W**2** as shown in FIG. **27**D. Thereafter, the laser beam L causes the separation at the interface between the laser absorption layer P**3** and the second wafer W**2**.

[0149] Subsequently, in a state where the transfer pad **120** attracts and holds the rear surface W**2***b* of the second wafer W**2**, the transfer pad **120** is raised as shown in FIG. **27**E to separate the second wafer W**2** from the laser absorption layer P**3**.

[0150] A case of processing the combined wafer T shown in FIG. **28**A to FIG. **28**D will be described. The combined wafer T has a structure in which a Ge-pMOS is stacked on an Si-nMOS. As shown in FIG. **28**A, the device layer D**1** and the front surface film F**1** are formed on the front surface W**1***a* of the first wafer W**1**. That is, the first wafer W**1** is the Si-nMOS.

[0151] Then, as shown in FIG. **28**B, the first wafer W**1** and the second wafer W**2**, which is the Ge-pMOS, are bonded to each other. A laser absorption layer P**4** made of an oxide film (SiO.sub.2film), the device layer D**2** made of Ge and the front surface film F**2** are stacked on the front surface W**2***a* of the second wafer W**2** in this order from the second wafer W**2**.

[0152] Thereafter, as shown in FIG. **28**B, the first wafer W**1** and the second wafer W**2** are bonded to each other. Specifically, the front surface film F**1** and the front surface film F**2** are bonded to each other.

[0153] Then, in the laser radiation device **31** of the wafer processing system **1**, the laser beam L is radiated in the pulse shape from the laser radiation unit **110** to the interface between the laser absorption layer P**4** and the device layer D**2** as shown in FIG. **28**C. Thereafter, the laser beam L causes the separation at the interface between the laser absorption layer P**4** and the device layer D**2**.

[0154] Subsequently, in a state where the transfer pad **120** attracts and holds the rear surface W**2***b* of the second wafer W**2**, the transfer pad **120** is raised as shown in FIG. **28**D to separate the laser absorption layer P**4** from the device layer D**2**. In the present exemplary embodiment as well, the separation position of the laser absorption layer P**4** may be adjusted by adjusting the absorption position of the laser beam L, i.e., the separation position of the laser absorption layer P**4**, as in the case shown in FIG. **24**A and FIG. **24**B, and the separation may occur at the interface between the second wafer W**2** and the laser absorption layer P**4**.

[0155] Any of the processing targets shown in FIG. **25**A to FIG. **28**D can achieve the same effects as obtained in above-described exemplary embodiments.

[0156] In the combined wafer T processed in the above-described exemplary embodiment, a reflective film R may be provided between the laser absorption layer P and the device layer D**2** as shown in FIG. **29**. That is, the reflective film R is formed on a surface of the laser absorption layer P opposite to an incident surface of the laser beam L. As the reflective film R, a material, e.g., a metal film, having a high reflectance to the laser beam L and a high melting point is used. The device layer D**2** is a functional layer and is different from the reflective film R.

[0157] In this case, the laser beam L output from the laser radiation unit **110** is transmitted through the second wafer W**2** and is almost completely absorbed by the laser absorption layer P. However, even if there is a laser beam L that cannot be completely absorbed, the laser beam L is reflected by the reflective film R. As a result, the laser beam L does not reach the device layer D**2**. Therefore, it is possible to reliably suppress damage to the device layer D**2**.

[0158] Further, the laser beam L reflected by the reflective film R is absorbed by the laser absorption layer P. Therefore, it is possible to improve the separation efficiency of the second wafer W**2**.

[0159] The exemplary embodiments disclosed herein are illustrative in all aspects and do not limit the present disclosure. The above-described exemplary embodiments may be omitted, replaced and modified in various ways without departing from the scope and the spirit of the appended claims.

[0160] According to the present disclosure, in the combined substrate in which the first substrate and the second substrate are bonded to each other, the device layer formed on the surface of the second substrate can be appropriately transferred to the first substrate.

[0161] The claims of the present application are different and possibly, at least in some aspects, broader in scope than the claims pursued in the parent application. To the extent any prior amendments or characterizations of the scope of any claim or cited document made during prosecution of the parent could be construed as a disclaimer of any subject matter supported by the present disclosure, Applicants hereby rescind and retract such disclaimer. Accordingly, the references previously presented in the parent applications may need to be revisited.

Claims

1. A substrate processing method of transferring, in a combined substrate in which a first substrate and a second substrate are bonded to each other, a device layer formed on the second substrate to the first substrate, wherein a first front surface film is formed on the first substrate, a laser absorption layer, a Si film, a second device layer, and a second front surface film are formed on the second substrate, in an order of the laser absorption layer, the Si film, the second device layer, and the second front surface film, from a front surface side of the second substrate, and the first front surface film of the first substrate and the second front surface film of the second substrate are bonded, wherein the substrate processing method comprises: radiating a laser light in a pulse shape from a rear surface side of the second substrate to the laser absorption layer, transferring the second device layer and the second front surface film to the first substrate by separating the second substrate from the first substrate at an interface between the laser absorption layer and the Si film or at an interface between the laser absorption layer and the second substrate.

2. The substrate processing method of claim 1, wherein a first device layer is formed between a front surface of the first substrate and the first front surface film.

3. The substrate processing method of claim 1, wherein the laser absorption layer is made of SiGe.

4. The substrate processing method of claim 1, wherein the laser absorption layer is made of Ge.

5. The substrate processing method of claim 1, wherein the laser light is radiated from an outer side to an inner side of the laser absorption layer in a diametrical direction, and radiation of the laser starts between an outer edge of the second substrate and an outer edge of the laser absorption layer, which is a bonding edge between the first substrate and the second substrate in the combined

substrate.
6. The substrate processing method of claim 1, wherein the laser light is radiated in an annular circular shape to the laser absorption layer by alternately performing a rotation of the combined substrate and a movement of the combined substrate in a diametrical direction.
7. The substrate processing method of claim 1, further comprising: cleaning the first substrate from which the second substrate has been separated.
8. The substrate processing method of claim 1, further comprising: etching the first substrate from which the second substrate has been separated.
9. The substrate processing method of claim 1, further comprising: performing a CMP (Chemical Mechanical Polishing) process on the first substrate from which the second substrate has been separated.
10. The substrate processing method of claim 1, wherein the laser light is radiated while the combined substrate is rotated, a rotation speed of the combined substrate is higher when the laser light is radiated to an inner side of the laser absorption layer in a diametrical direction than when the laser beam is radiated to an outer side in the diametrical direction, and a frequency of the laser light is higher when the laser light is radiated to the outer side of the laser absorption layer than when the laser beam is radiated to the inner side.
11. The substrate processing method of claim 1, wherein the first front surface film is an oxide film, and the second front surface film is an oxide film.
12. A substrate processing apparatus for transferring, in a combined substrate in which a first substrate and a second substrate are bonded to each other, a device layer formed on a front surface of the second substrate to the first substrate, wherein a first front surface film is formed on the first substrate, a laser absorption layer, a Si film, a second device layer, and a second front surface film are formed on the second substrate, in an order of the laser absorption layer, the Si film, the second device layer, and the second front surface film, from a front surface side of the second substrate, and the first front surface film of the first substrate and the second front surface film of the second substrate are bonded, wherein the substrate processing apparatus comprises: a holder configured to hold a rear surface of the first substrate; a laser radiation unit configured to radiate a laser light in a pulse shape from a rear surface side of the second substrate to the laser absorption layer in a state where the holder holds the first substrate; a motor configured to rotate the holder; a slider configured to move the holder in a diametrical direction; and a controller and a storage storing a computer program, wherein the storage and the computer program are configured, with the controller, to control the motor, the slider and the laser radiation unit, wherein the controller controls the motor, the slider and the laser radiation unit to radiate the laser light in an annular circular shape to the laser absorption layer by alternately performing a rotation of the holder and a movement of the holder in the diametrical direction.
13. The substrate processing apparatus of claim 12, wherein a first device layer is formed between a front surface of the first substrate and the first front surface film.
14. The substrate processing apparatus of claim 12, wherein the controller controls the laser irradiation unit such that the laser light is radiated from an outer side to an inner side of the laser absorption layer in the diametrical direction, and radiation of the laser starts between an outer edge of the second substrate and an outer edge of the laser absorption layer, which is a bonding edge between the first substrate and the second substrate in the combined substrate.
15. A substrate processing system for transferring, in a combined substrate in which a first substrate and a second substrate are bonded to each other, a device layer formed on a front surface of the second substrate to the first substrate, wherein a first front surface film is formed on the first substrate, a laser absorption layer, a Si film, a second device layer, and a second front surface film are formed on the second substrate, in an order of the laser absorption layer, the Si film, the second device layer, and the second front surface film, from a front surface side of the second substrate, and the first front surface film of the first substrate and the second front surface film of the second

substrate are bonded, wherein the substrate processing system comprises: a holder configured to hold a rear surface of the first substrate; a laser radiation unit configured to radiate a laser light in a pulse shape from a rear surface side of the second substrate to the laser absorption layer in a state where the holder holds the first substrate; and a transfer unit configured to transfer the second device layer and the second front surface film to the first substrate by separating the second substrate from the first substrate at an interface between the laser absorption layer and the Si film or at an interface between the laser absorption layer and the second substrate.

16. The substrate processing system of claim 15, wherein a first device layer is formed between a front surface of the first substrate and the first front surface film.

17. The substrate processing system of claim 15, further comprising: a cleaning device configured to clean the first substrate from which the second substrate has been separated.