FIG. 22 is an explanatory diagram schematically illustrating the formation of the separation starting point according to the second exemplary embodiment.

FIG. 23 is an explanatory diagram illustrating an exemplary operation of bevel fill and separation according to the second exemplary embodiment.

FIG. 24 is an explanatory diagram schematically illustrating formation of a separation starting point according to a third exemplary embodiment.

FIG. 25A to **FIG. 25C** are explanatory diagrams illustrating a wafer processing according to a comparative example.

DETAILED DESCRIPTION

[0009] In a manufacturing process of a semiconductor device, in a combined wafer in which two sheets of semiconductor substrates (hereinafter, referred to as “wafers”) are bonded to each other, a device layer formed on a front surface of a first wafer is transferred to a second wafer. When the device layer is transferred from the first wafer to the second wafer, laser light is radiated to a laser absorption layer included in the first wafer to reduce a bonding force between the first wafer and the second wafer and separate the first wafer from the second wafer. The separated first wafer is reused and then bonded to a subsequent second wafer.

[0010] At an outer peripheral portion of a combined wafer T, a non-bonded region B in which bevel portions of a first wafer W and a second wafer S are not bonded to each other may be formed (see **FIG. 2**). The present inventors have diligently studied and found that during the separation of the first wafer W, even if the bonding force at the separation surface of the first wafer W is reduced, the separation may preferentially occur in another region near the non-bonded region B, rather than at the separation surface. For example, when an upward force Fup

is applied to an outer peripheral portion We of the first wafer W as shown in **FIG. 25A**, a portion of a bevel of the first wafer W, corresponding to the non-bonded region B, may be separated from the combined wafer T while still bonded to the first wafer W as shown in **FIG. 25B**. In another example, as shown in **FIG. 25C**, the separation may progress such that a device region of the second wafer S (or the first wafer W) is torn away from an outer peripheral edge of a bonding surface between the first wafer W and the second wafer S, and extends across a front surface of the second wafer S.

[0011] Although the reason for such inappropriate separation is not clear, it is assumed that a stress, which is concentrated on the separation surface, is also concentrated, besides the separation surface, in a region near the outer peripheral edge of the bonding surface between the first wafer W and the second wafer S, and the separation is initiated from this region.

[0012] When a portion of the bevel is lost as shown in the example of **FIG. 25B**, a region, in which a device can be formed, (device-formable region) of the first wafer W separated from the combined wafer T becomes limited, which may result in a reduction in productivity. Moreover, in a process in which the bonding and the separation are repeated two or more times, such bevel loss is also repeated, which may lead to a significant reduction in the device-formable region.

[0013] When the separation progresses such that the device region of the second wafer S (or the first wafer W) is torn away as shown in the example of **FIG. 25C**, the productivity may be directly reduced.

[0014] The technique according to the present disclosure enables the appropriate separation of the first substrate and the second substrate in the combined substrate in which the first substrate and the second substrate are bonded to each other. Hereinafter, a manufacturing method of a semiconductor device according to the present exemplary embodiment will be

described with reference to the accompanying drawings. Further, in the present specification and drawings, parts having substantially the same functions and configurations will be assigned same reference numerals, and redundant description thereof will be omitted.

[0015] In the manufacturing method of the semiconductor device according to the present exemplary embodiment, the first wafer W as a first substrate is prepared first (see St1 of **FIG. 1**) and the second wafer S as a second substrate is prepared (see St2 of **FIG. 1**). The first wafer W and the second wafer S may be prepared in parallel. Hereinafter, as shown in **FIG. 2** and **FIG. 3A** to **FIG. 3C**, in the first wafer W, a surface bonded to the second wafer S is referred to as a front surface Wa, and a surface opposite to the front surface Wa is referred to as a rear surface Wb. Likewise, in the second wafer S, a surface bonded to the first wafer W is referred to as a front surface Sa, and a surface opposite to the front surface Sa is referred to as a rear surface Sb.

[0016] The first wafer W prepared in St1 is, for example, a semiconductor wafer such as a silicon substrate. In an exemplary embodiment, the first wafer W has a substantially circular plate shape. As shown in **FIG. 3A**, a stacked film composed of a plurality of films is formed on the front surface Wa of the first wafer W. The stacked film includes, in order from the front surface Wa side, a laser absorption layer P, an etching stop layer Q, a device layer Dw, and a front surface film Fw. Each of the laser absorption layer P, the etching stop layer Q, the device layer Dw, and the front surface film Fw is formed on the first wafer W by a process including, for example, CVD (Chemical Vapor Deposition) in a film formation apparatus (not shown) or RIE (Reactive Ion Etching) in an etching apparatus (not shown). Further, another desired film may be formed, as a component of the stacked film, between any adjacent layers among the laser absorption layer P, the etching stop layer Q, the device layer Dw, and the front surface film Fw. Details of the formation of the stacked film will be described later.

performed using dry etching or wet etching. Accordingly, the laser absorption layer P is selectively etchable relative to the front surface Wa of the first wafer W. In an exemplary embodiment, when a sacrificial layer is provided between the laser absorption layer P and the first wafer W, the selective etching is first performed between the laser absorption layer P and the sacrificial layer, and then the selective etching is performed between the sacrificial layer and the front surface Wa of the first wafer W.

[0037] After the laser absorption layer P is removed from the first wafer W, the same processing as St1 is subsequently performed on the first wafer W, and the laser absorption layer P, the etching stop layer Q, the first device layer Dw, and the front surface film Fw are formed on the front surface Wa. In this way, the first wafer W is reused for a subsequent second wafer S. Even though the laser absorption layer P has been removed, the removed first wafer W is a bare wafer with no film on the front surface Wa and thus may be reused as the second wafer S in a subsequent process.

[0038] The third wafer U separated in St13 is also reused (St21 of **FIG. 1**). In St21, reuse of the third wafer U is performed in the same manner as the reuse of the first wafer W in St20.

[0039] Hereinafter, as a manufacturing method according to an exemplary embodiment, **FIG. 8** illustrates a case where at least a portion of a 3D NAND memory cell array is formed in the device layer Dw of the first wafer W in the preparation of the first wafer W (St1 of **FIG. 1**). The device layer Dw includes a memory hole H formed by the following exemplary method.

[0040] Specifically, the preparation of the first wafer W according to the present exemplary embodiment (St1 of **FIG. 1**) includes processes shown in **FIG. 9** and **FIG. 10A** to **FIG. 10C**. **FIG. 10A** to **FIG. 10C** illustrate states of the device layer Dw in main processes. The same applies to preparation of the third wafer U in St9 of **FIG. 1**.

Th. In the example shown in **FIG. 17** according to the present exemplary embodiment, the separation surface Sf is the interface between the laser absorption layer P and the first wafer W. However, the separation surface Sf may also be, for example, an inner surface of the laser absorption layer P or an interface between the laser absorption layer P and the etching stop layer Q according to the above-described exemplary embodiment.

[0067] In an exemplary embodiment, the third outer peripheral position E3 may be determined such that D1/D2 is greater than a predetermined threshold Th2.

[0068] In the bevel fill according to the first exemplary embodiment, inappropriate separation as described above with reference to **FIG. 25A** to **FIG. 25C** can be suppressed by filling the filler G to the predetermined second outer peripheral position E2 located radially inward of the first outer peripheral position E1.

[0069] Although the reason why the inappropriate separation is suppressed by the bevel fill according to the first exemplary embodiment is not clear, the following operation example can be assumed. When the upward force Fup is applied to the outer peripheral portion We of the first wafer W as shown in **FIG. 18**, the stresses σ1 and σ2 are assumed to act near the outermost position of the bonding interface Bf between the first wafer W and the second wafer S, and near the third outer peripheral position E3, respectively. Since the contribution of the stress σ2 to the separation is greater than that of the stress σ1, it is assumed that a crack Cr originates near the third outer peripheral position E3.

[0070] Further, as shown in **FIG. 19**, if the laser absorption layer P is formed extending to the non-bonded region B, the crack Cr originating from the third outer peripheral position E3 may not occur when the upward force Fup is applied to the outer peripheral portion We of the first

wafer W. It is assumed that this is because the separation at the separation surface Sf, which extends to the non-bonded region B, preferentially occurs.

[0071] Since the third outer peripheral position E3 is determined such that the difference between D1 and D2 is greater than a predetermined threshold Th, the inappropriate separation as described above can be further suppressed. Although the reason is not clear, the following operation example can be assumed. For the crack Cr shown in **FIG. 18**, it is assumed that a more suitable separation occurs when the crack Cr propagates toward the separation surface Sf. Therefore, it is assumed that since the third outer peripheral position E3 is determined as described above, the distance between the third outer peripheral position E3 and the separation surface Sf can be reduced, which facilitates the propagation of the crack Cr toward the separation surface Sf.

[0072] The present inventors have diligently studied and found that the above-described inappropriate separation tends to occur in the first wafer W having a stacked film with the large first distance D1. Herein, it is assumed that the stacked film with the large first distance D1 refers to a case where, as in the first wafer W according to the above-described exemplary embodiment, the device layer Dw is formed by repeating a plurality of processes, and, thus, the thickness of the entire stacked film increases. In particular, when the device layer Dw includes a memory cell array of a NAND-type flash memory, a considerable increase in the thickness of the stacked film including the device layer Dw is observed.

[0073] In the bevel fill according to the first exemplary embodiment, the above-described inappropriate separation can be suppressed even when the combined wafer T including the first wafer W having the stacked film with the large first distance D1 is separated.

[0074] Hereinafter, the bevel fill and the separation according to the second exemplary embodiment will be described. The bevel fill and the separation according to the second

above-described inappropriate separation. However, in the separation according to the second exemplary embodiment, as shown in **FIG. 23**, when the upward force Fup is applied to the outer peripheral portion We of the first wafer W, a stress tends to concentrate in a region near the separation starting point A at the interface between the filler G and the front surface film Fw. Thus, it is assumed that the crack Cr originates from this region. Further, since the separation starting point A is formed along the entire circumference of the filler G, the crack Cr uniformly propagates along the entire circumference. Thus, it is assumed that separation is appropriately performed.

[0088] Hereinafter, the bevel fill and the laser radiation according to the third exemplary embodiment will be described. The bevel fill and the laser radiation according to the third exemplary embodiment is performed for the combined wafer T, and may be performed for the first combined wafer T1 in St4 and St5 or for the second combined wafer T2 in St11 and St12 of the above-described exemplary embodiment. In **FIG. 24**, depiction of the etching stop layer Q and the device layer Dw of the first wafer W and the device layer Ds of the second wafer S according to the above-described exemplary embodiment is omitted for convenience of description.

[0089] The bevel fill according to the third exemplary embodiment is identical to that of the second exemplary embodiment. As shown in **FIG. 20**, the filler G is filled up to the predetermined second outer peripheral position E2 which is determined based on the first outer peripheral position E1 of the front surface film Fw of the first wafer W, which serves as the first bonding layer of the combined wafer T, and is located radially outward of the first outer peripheral position E1.

[0090] Then, the separation starting point A is formed in the filler G of the combined wafer T after the bevel fill. As shown in **FIG. 24**, the separation starting point A is formed by radiating laser light to the filler G. The laser radiation is the same as the radiation of the laser light L to the

WE CLAIM

[Claim 1] A semiconductor device manufacturing method, comprising:

performing, in a non-bonded region of a combined substrate which includes a first substrate having a laser absorption layer and a first bonding layer and a second substrate having a second bonding layer and in which the first bonding layer and the second bonding layer are bonded to each other, bevel fill by injecting a filler up to a predetermined second outer peripheral position which is determined based on a first outer peripheral position in the first bonding layer;

radiating laser to the laser absorption layer; and

separating the first substrate from the second substrate in the combined substrate.

[Claim 2] The semiconductor device manufacturing method of Claim 1,

wherein the second outer peripheral position is located radially inward of the first outer peripheral position, and

the method includes:

after radiating the laser to the laser absorption layer of the combined substrate in which the second outer peripheral position is located radially inward of the first outer peripheral position, the first substrate is separated from the second substrate.

[Claim 3] The semiconductor device manufacturing method of Claim 2,

wherein when a distance between a separation surface, which is formed between the first substrate and the second substrate and is formed by radiating the laser, and a bonding interface between the first bonding layer and the second bonding layer is set as a first distance,

when a distance between the separation surface and a third outer peripheral position, which is an outermost position in a radial direction at a contact interface between the first bonding layer and the filler, is set as a second distance, and

the third outer peripheral position is previously determined such that a difference between the first distance and the second distance is greater than a predetermined threshold.

[Claim 4] The semiconductor device manufacturing method of Claim 1,

wherein the second outer peripheral position is located radially outward of the first outer peripheral position, and

the method includes:

forming, before the separating of the first substrate from the second substrate, a separation starting point along an entire circumference of the filler when viewed from top.

[Claim 5] The semiconductor device manufacturing method of Claim 4,

wherein the separating of the first substrate from the second substrate includes:

forming the separation starting point by using a starting point forming device.

[Claim 6] The semiconductor device manufacturing method of Claim 5,

wherein the starting point forming device includes a blade, and

the method includes:

forming, while the blade remains inserted in the filler, the separation starting point by rotating the blade and the combined substrate relative to each other.

[Claim 7] The semiconductor device manufacturing method of Claim 4, further comprising:

forming the separation starting point by radiating laser to the laser absorption layer and radiating laser light to the filler.

[Claim 8] The semiconductor device manufacturing method of Claim 1, further comprising:

forming an etching stop layer on the laser absorption layer; and

forming a device layer on the etching stop layer.

[Claim 9] The semiconductor device manufacturing method of Claim 8, further comprising:

forming a wiring layer; and

forming a front surface film for bonding in the first substrate.

[Claim 10] The semiconductor device manufacturing method of Claim 8, further comprising:

performing, after the separating of the first substrate from the second substrate, surface treatment of a separation surface of the second substrate onto which the device layer is transferred,

wherein the etching stop layer is formed of a material that allows selective etching with respect to the separation surface, and

the surface treatment includes removing the etching stop layer by performing the selective etching between the etching stop layer and the separation surface.

[Claim 11] The semiconductor device manufacturing method of Claim 10,

wherein the surface treatment includes exposing at least a portion of the device layer from the separation surface.

[Claim 12] The semiconductor device manufacturing method of Claim 8,

wherein the forming of the device layer includes:

forming a stacked film on the etching stop layer; and

forming a deep hole by etching the stacked film,

the forming of the etching stop layer includes:

forming an etch stop structure at a portion of the etching stop layer corresponding to a predetermined position where the deep hole is to be formed in the device layer, and

the etching for forming the deep hole stops at the etch stop structure.

[Claim 13] The semiconductor device manufacturing method of Claim 12,

wherein the etch stop structure includes a pad formed of one or more materials selected from titanium nitride, tungsten, and tungsten silicide.

[Claim 14] The semiconductor device manufacturing method of Claim 1, further comprising:

removing, after the separating of the first substrate from the combined substrate, the filler filled in the non-bonded region by the bevel fill.

[Claim 15] The semiconductor device manufacturing method of Claim 14, further comprising:

performing, after the separating of the first substrate from the combined substrate, surface treatment of a separation surface of the combined substrate from which the first substrate is separated; and

performing, after the removing of the filler and before the performing of the surface treatment of the separation surface, the bevel fill again in the non-bonded region of the combined substrate.

[Claim 16] The semiconductor device manufacturing method of Claim 8,

wherein the device layer includes at least a portion of a memory cell array.

[Claim 17] The semiconductor device manufacturing method of Claim 16,

wherein the second substrate includes another device layer, and

the another device layer includes at least a portion of a peripheral circuit for controlling the memory cell array.

[Claim 18] The semiconductor device manufacturing method of Claim 1, further comprising:

forming a second combined substrate by bonding a third substrate having a laser absorption layer to the combined substrate;

performing the bevel fill again in a non-bonded region of the second combined substrate;

radiating laser to the laser absorption layer of the third substrate; and

separating the third substrate from the second substrate in the second combined substrate.

[Claim 19] A semiconductor device manufacturing system, comprising:

a laser radiation apparatus configured to radiate laser, after performing, in a non-bonded region of a combined substrate which includes a first substrate having a laser absorption layer and a first bonding layer and a second substrate having a second bonding layer and in which the first bonding layer and the second bonding layer are bonded to each other, bevel fill by injecting a filler up to a predetermined second outer peripheral position which is determined based on a first outer peripheral position in the first bonding layer, to the laser absorption layer; and

a separation apparatus configured to separate the first substrate from the second substrate in the combined substrate.

[Claim 20] The semiconductor device manufacturing system of Claim 19, further comprising:

a bevel fill apparatus configured to perform the bevel fill in the non-bonded region of the combined substrate.