

**METHOD FOR PREPARING THE REMAINDER OF A DONOR SUBSTRATE, SUBSTRATE
PRODUCED BY SAID METHOD, AND USE OF SUCH A SUBSTRATE**

FIELD OF THE INVENTION

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The present invention relates to a method for preparing the remainder of a donor substrate. The substrates produced by this method can be used to form an inexpensive structure on insulator of SOI type, for example for use in the field of microelectronics, for the manufacture of MEMS, etc.

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TECHNOLOGICAL BACKGROUND OF THE INVENTION

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Smart Cut™ technology is a technology widely used in the semiconductor field for the formation of a thin layer on a support substrate. This technology enables the removal of a thin layer from one face of a donor substrate by fracturing at a weakened plane (or fracture plane) formed by implanting light species. The donor substrate remaining after the transfer of the thin layer is referred to as "remainder" and generally comprises an annular step corresponding to the non-removed part of the face of the donor substrate.

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The present invention relates more particularly to the preparation of such a remainder in order to make it reusable. Such methods for preparing a remainder produced by the Smart Cut™ method are known. Mention may be made, by way of example, of documents US20090061545, US20100200854. These methods are generally complex and comprise the removal of the annular step. A conventional method of the prior art comprises the following steps: a first polishing to partially remove the annular step from the remainder, then a "double-sided polishing" (polishing of both faces simultaneously), followed by a chemical polishing in order to entirely remove the step and obtain a surface with satisfactory surface properties for subsequent use. These methods may also comprise other additional steps such as a deoxidation.

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The methods of the prior art are often expensive, long and may lead to a significant loss of material, in particular for the methods

based on "double-sided polishing". Depending on the subsequent use which will be made of the remainder, it may be beneficial to reduce this loss of materials.

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OBJECT OF THE INVENTION

Embodiments of the invention seek to provide a method for preparing a remainder of a donor substrate that at least partly solves the above-mentioned problem. Embodiments of the invention also seek to provide a simpler, less expensive preparation method that causes less loss of material than those of the prior art.

BRIEF DESCRIPTION OF THE INVENTION

15 An aspect of the invention provides a method for preparing the remainder of a donor substrate, a layer having been removed from the donor substrate by delamination in a plane weakened by ion implantation, the remainder comprising, on a main face, an annular step corresponding to a non-removed part of the donor substrate, the method comprising the deposition of a smoothing oxide on the main face
20 of the remainder in order to fill the inner space defined by the annular step and to cover at least part of the annular step, as well as heat treatment for densification of the smoothing oxide.

25 According to other advantageous non-limiting features of the invention, taken alone or according to any technically feasible combination:

- the smoothing oxide belongs to the SOG (Spin-On Glass) family;
- the densification heat treatment has a temperature of between
30 225°C and 900°C;
- the densification heat treatment is carried out under a nitrogen (N₂) atmosphere;
- the deposition of smoothing oxide is carried out under conditions leading to the formation of a layer having a thickness at
35 least equal to one and a half times the height of the annular step;
- the method comprises a step of preparing the main surface of the remainder, before the deposition step;

- the step of preparing the main surface of the remainder comprises the removal of a peripheral zone of the main surface damaged by ion implantation.

5 Another aspect of the invention relates to a substrate comprising a remainder of a donor substrate, a layer having been removed from the donor substrate by delamination in a plane weakened by ion implantation, the remainder comprising on a main face an annular step corresponding to a non-removed part of the donor substrate, the
10 substrate also comprising an oxide layer on the main face of the remainder, the oxide layer filling the inner space defined by the annular step and covering at least part of the annular step.

According to other advantageous non-limiting features of the invention, taken alone or according to any technically feasible
15 combination:

- the oxide layer has a thickness at least equal to one and a half times the height of the annular step;
- the remainder comprises a surface oxide layer;
- the donor substrate consists of silicon.

20 Another aspect of the invention relates to the use of a substrate, which comprises providing a substrate prepared as specified above, assembling said substrate with a donor substrate and thinning the donor substrate to form a structure on insulator (for example of SOI-
25 Silicon on Insulator-type).

The assembly may comprise a heat treatment at a temperature of between 100°C and 500°C.

30 **BRIEF DESCRIPTION OF THE DRAWINGS**

Other features and advantages of the invention will emerge from the following detailed description of the invention with reference to the appended figures, in which:

- Figure 1 depicts the various steps of an example of a layer
35 removal method;
- Figure 2 depicts the remainder obtained after the layer removal;
- Figure 3 depicts the various steps of a first embodiment according to the invention;

- Figure 4 depicts the various steps of a second embodiment according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

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For the sake of simplifying the following description, the same references are used for elements that are identical or perform the same function in the prior art.

The figures are schematic depictions which, for the sake of
10 readability, are not to scale.

The invention relates to a method for preparing the remainder of a donor substrate in order to make it usable.

This remainder is generally obtained following the removal, from
15 the donor substrate 1, of a thin layer 5 by delamination in a plane 3 weakened by ion implantation, the remainder 1' comprising, on a main face 10, an annular step 11 corresponding to a non-removed part of the donor substrate 1. The thin layer 5 is transferred to a support
substrate 4.

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The donor substrate 1 and the support substrate 4 may consist of any materials. This may be a semiconductive material (such as silicon, SiGe, germanium, gallium nitride), an insulator (such as sapphire or glass) or a piezoelectric material (such as lithium tantalate or
25 lithium niobate).

The donor substrate 1 and/or the support substrate 4 may be provided with a surface insulator layer 2 comprising for example a silicon or aluminum oxide or a silicon or aluminum nitride. It may thus have been formed by deposition, oxidation or nitriding, as
30 appropriate.

The support substrate 1 and the support substrate 4 may advantageously be disk-shaped silicon wafers, the diameter of which is typically 200 mm, 300 mm or even 450 mm. At least one of these wafers may have a surface insulator layer, such that a silicon-on-insulator
35 wafer is obtained at the end of the method. However, the invention is not limited to these materials, this shape or these dimensions alone.

Figure 1 depicts the various steps of an example of a layer removal method of the Smart Cut type, resulting in the remainder 1' used by the invention.

5 This type of method comprises providing a donor substrate 1, illustrated by Figure 1A, optionally followed by a step of oxidation of the donor substrate 1 illustrated by Figure 1B with the formation of a surface oxide layer 2 as described previously.

10 Next, a first step, illustrated by Figure 1C, of formation of a plane 3 weakened by implantation of light species into the donor substrate 1 is carried out, so as to form a thin layer 5 between this plane and the implanted surface of the donor substrate 1. The weakened plane 3 is typically produced by implantation of hydrogen and/or of
15 noble gas. Thus, the light species may be selected from hydrogen and helium ions at doses of between 5×10^{15} and 1×10^{17} at/cm².

As regards the implantation energy, it is typically between 10 keV and 200 keV and defines the implantation depth of the ions.

20 In a second step, illustrated by Figure 1D, subsequent to the first step, the support substrate 4 is assembled with the implanted surface of the donor substrate 1, to form an assembly to be fractured. This assembly is preferentially produced by molecular adhesion, i.e.
25 by direct adhesion of the surfaces to one another without adding adhesive material (aside from water), and by using adhesion forces mainly of the van der Waals or covalent type.

30 The assembly step may be preceded by any prior surface treatment of the substrate 1 and of the support 4, such as one or more cleaning operations, plasma activation, etc.

35 In a following step, illustrated by Figure 1E, the assembly to be fractured is subject to a fracturing heat treatment step. This step aims to develop microcavities, platelets, and/or other types of defects that are precursors to the fracture in the weakened plane 3. It leads to the initiation and propagation of the fracture wave along

the weakened plane 3 so as to transfer the thin film 5 to the support substrate 4.

5 This fracturing heat treatment may also help to strengthen the degree of adhesion between the donor substrate 1 and the support substrate 4.

10 At the end of this fracturing heat treatment step, and as depicted in Figure 1E, both the thin layer 5 transferred to the support 4 and a remainder 1', depicted in more detail in Figure 2, of the donor substrate 1 from which the useful layer 5 was removed are obtained.

15 The remainder 1' comprises, on a main face 10, an annular step 11 corresponding to a non-removed part of the donor substrate 1. This is a peripheral zone where the degree of adhesion between the donor substrate 1 and the support substrate 4 is insufficient to enable the layer to be removed. The width of the step 11 may range from 0.5 to 3 mm and the height thereof may range from 100 nm to 3.5 micrometers or 20 even 4 micrometers.

The presence of the step 11 and the surface properties of the main face 10 do not enable direct reuse and necessitate the preparation of the remainder 1' before re-use, in particular in a 25 method of the Smart Cut™ type or a layer transfer method. The present invention proposes such a preparation of the remainder 1'.

First embodiment

30 According to a first embodiment, depicted in Figures 3A and 3B, the method for preparing the remainder 1' comprises two steps: a deposition of a smoothing oxide 6 on the main face 10 of the remainder 1', and a heat treatment for densification of the smoothing oxide.

35 The smoothing oxide 6 is generally selected from the SOG (Spin-On Glass) family, which have the property of being in liquid state at room temperature but may be densified, and made solid, using a suitable heat treatment.

The step of deposition of a smoothing oxide 6 consists in depositing a layer of smoothing oxide 6 on the main face 10 of the

remainder 1' in order to fill the inner space defined by the annular step 11 and to cover at least part of the annular step 11. The deposition of smoothing oxide 6 may also preferably be carried out under conditions leading to the formation of a layer having a thickness at least equal to one and a half times the height of the annular step 11, as illustrated in Figure 3B. In order to carry out the planarization of the main surface 10 by the smoothing oxide 6, the remainder 1' is rotated on its support so that it can be distributed by centrifugal force.

The step of densification heat treatment consists in exposing the remainder provided with the layer of smoothing oxide 6 to a temperature of between 225°C and 850°C, or even 900°C. This heat treatment may last approximately 1 h and be carried out under a nitrogen atmosphere.

At the end of this step, the surface of the smoothing oxide 6 is sufficiently smooth, with a roughness typically of less than 5 Å RMS (AFM measurement 5x5 μm^2), to satisfy the requirements of its subsequent use. The layer of smoothing oxide 6 has an elasticity, viscosity and/or breaking strength which are sufficient to prevent the possible exfoliation of the bubbles associated with the weakened plane present under the step 11 during the densification annealing or during steps leading to the exposure of the treated substrate to high temperatures.

At the end of these treatments, a substrate 7 is obtained, illustrated by Figure 3B, comprising a remainder 1' of a donor substrate 1, the remainder 1' comprising, on a main face 10, an annular step 11 corresponding to a non-removed part of the donor substrate 1. The remainder 1' may also comprise a surface oxide layer 2 obtained during the steps for transfer of the thin layer 5 from the donor substrate 1 to the support substrate 4. The donor substrate 1 may consist of silicon.

The substrate 7 also comprises an oxide layer 6 on the main face 10 of the remainder 1', the oxide layer 6 filling the inner space defined by the annular step 11 and covering at least part of the annular step 11. Preferably, the oxide layer 6 has a thickness at least equal to one and a half times the height of the annular step 11.

Second embodiment

According to a second embodiment, depicted in Figures 4A to 4D, the method for preparing the remainder 1' comprises an additional step of preparing the main surface 10 of the remainder 1' before the step
5 of deposition of the smoothing oxide 6.

Indeed, there is a risk of exfoliation of the annular step 11, or of a part thereof, at the residual implantation defects, when the latter remain present in the remainder 1' as can be seen in Figures 3A and 4A. This problem may arise with the first embodiment even if it is
10 advantageously reduced by covering the step 11 with the smoothing oxide 6, by virtue in particular of its viscosity, elasticity, and breaking strength properties. However, it remains possible to further reduce this risk.

15 In order to reduce this risk, this second embodiment provides a step of preparing the main surface 10 of the remainder, with the aim of eliminating the part of the step 11 subject to the exfoliation. This step of preparing the main surface 10 of the remainder 1' may thus comprise:

20 - the preliminary removal of the surface oxide layer 2 (Figure 4B);

- elimination of material, for example by chemical etching, configured to remove a thin layer of the main surface 10 of the remainder 1' and eliminate the part of the step 11 damaged by ion
25 implantation (Figure 4C). In other words, the step of preparing the main surface 10 comprises the removal of a peripheral zone of this surface, which has been damaged by ion implantation.

The step of removal of the oxide layer, depicted by Figure 4B, makes it possible to expose the damaged part of the step 11 to be
30 treated. This may for example be a wet chemical etching, under cold conditions, of the oxide with a dilute hydrofluoric acid (HF) solution.

The step of chemical etching of the remainder enables the removal of the part of the step 11 damaged by the ion implantation and therefore subject to the exfoliation. This may, for example, be a wet
35 chemical etching, under hot conditions, of the remainder 1' by a basic aqueous solution of TMAH or KOH to remove a thickness of the remainder 1' over a depth at least equivalent to the initial step height.

It is also possible to consider other methods for preparing the surface, such as polishing and/or partial trimming of the plate edge, for example.

This step of preparing the surface implements simple and inexpensive treatments which do not however make it possible to obtain an entirely planar surface. At the end of these treatments, and regardless of the technology used during the surface preparation step, the remainder 1' still has a peripheral topography that defines a residual annular step 11.

At the end of the surface preparation step, the steps described in relation to the first embodiment are reproduced, that is to say that the smoothing oxide is deposited on the main face 10 of the remainder, in order to fill the inner space defined by the annular step 11 and to cover at least part of the annular step 11; and a heat treatment for densification of the smoothing oxide 6 is applied.

At the end of this method, a substrate 7 is obtained, illustrated by Figure 4D, comprising a remainder 1' of the donor substrate 1, comprising, on the main face 10 thereof, a residual annular step 11. The remainder 1' may also comprise a surface oxide layer 2 (Figure 3B). The substrate 7 also comprises an oxide layer 6 on the main face 10 of the remainder 1', the oxide layer 6 filling the inner space defined by the annular step 11 and covering at least part of the annular step 11.

A method in accordance with the invention has the advantage of reducing the loss of material, of not requiring the complete removal of the step 11 of the main face 10 of the remainder 1, and of providing a perfectly planar face. In particular, it is possible to dispense with a step of "double-sided polishing" which is generally necessary in the solutions of the prior art. It makes it possible to produce a remainder 7 in a small number of steps, reducing the loss of material, and having satisfactory surface properties to be used, for example, as a recipient substrate for the manufacture of substrates for MEMS.

Use

The substrate 7 produced by a method in accordance with the invention can be used as recipient substrate for the manufacture of a substrate on insulator, for example of SOI type.

The use of this substrate 7 comprises the assembly thereof with a donor substrate, then the thinning of this donor substrate to form a structure on insulator.

The properties of the smoothing oxide layer 6 make it possible to produce the assembly without applying a high-temperature adhesion heat treatment.

The substrate 7 may thus preferably be used as a support in a layer transfer method, the assembling possibly comprising a heat treatment that may be carried out at low temperature, typically between 100°C and 900°C. Even more preferentially, said heat treatments are carried out at temperatures of between 100°C and 500°C, and the transferred layer may then be provided with microelectronics devices for an application in the field of 3D integration.

Of course, the invention is not limited to the embodiments described and variant embodiments can be added thereto without departing from the scope of the invention as defined by the claims.

CLAIMS

1. A method for preparing the remainder (1') of a donor substrate (1),
a layer (5) having been removed from the donor substrate (1) by
5 delamination in a plane (3) weakened by ion implantation, the
remainder (1') comprising on a main face (10) an annular step (11)
corresponding to a non-removed part of the donor substrate, the
method comprising:
 - a. the deposition of a smoothing oxide (6) on the main face of
10 the remainder (10) in order to fill the inner space defined by
the annular step (11) and to cover at least part of the
annular step (11);
 - b. a heat treatment for densification of the smoothing oxide (6).
- 15 2. The preparation method according to the preceding claim, wherein
the smoothing oxide (6) belongs to the SOG (Spin-On Glass) family.
3. The preparation method according to one of the preceding claims,
wherein the densification heat treatment has a temperature of
20 between 225°C and 900°C.
4. The preparation method according to one of the preceding claims,
wherein the densification heat treatment is carried out under a
nitrogen (N₂) atmosphere.
- 25 5. The preparation method according to the preceding claim, wherein
the deposition of smoothing oxide (6) is carried out under
conditions leading to the formation of a layer having a thickness
at least equal to one and a half times the height of the annular
30 step (11).
6. The preparation method according to one of the preceding claims,
comprising, before the deposition step, a step of preparing the
main surface (10) of the remainder (1') comprising the removal of
35 a peripheral zone of the main surface (1a) damaged by ion
implantation.

7. A substrate (7) comprising:

- a. a remainder (1') of a donor substrate (1), a layer (5) having been removed from the donor substrate (1) by delamination in a plane (3) weakened by ion implantation, the remainder (1') comprising on a main face (10) an annular step (11) corresponding to a non-removed part of the donor substrate (1);
- b. an oxide layer (6) on the main face of the remainder (1'), the oxide layer (6) filling the inner space defined by the annular step and covering at least part of the annular step of the remainder.

8. The substrate (7) according to the preceding claim, wherein the oxide layer has a thickness at least equal to one and a half times the height of the annular step.

9. The substrate (7) according to one of the two preceding claims, wherein the remainder (1') comprises a surface oxide layer (2).

10. The substrate (7) according to one of claims 7 to 9, wherein the donor substrate (1) consists of silicon.

11. A use of a substrate (7), comprising:

- a. providing a substrate (7) in accordance with one of claims 7 to 10;
- b. assembling the substrate (7) with a donor substrate;
- c. thinning the donor substrate to form a structure on insulator.

12. The use of a substrate (7) according to the preceding claim, wherein the assembly comprises a heat treatment at a temperature of between 100°C and 500°C.