

Process For Transferring Thin Semiconductor Layers and Process for Obtaining A Donor Wafer for Such A Transfer Process

The present invention relates in general to the fabrication of semiconductor substrates, especially for the electronics, optoelectronics or optics industries.

- 5 More particularly, the invention relates to the production of an assembly of two wafers, at least one of which is a semiconductor.

Typically, such an assembly is effected by molecular
10 adhesion or wafer bonding and, after this assembling operation, undergoes a certain number of technological steps for producing circuits or components in the aforementioned fields.

- 15 In particular, in a substrate fabrication cycle of the Smart-Cut (registered trade mark) type, involving the implantation of gaseous species at a controlled depth in a bulk donor wafer in order to create a region of weakness, and the application of stresses to cause at
20 the end a separation at this region of weakness, the wafer must undergo, after this separation, a number of operations and especially:

- mechanical, chemical-mechanical or other polishing steps carried out on the donor wafer in order
25 to recycle the latter;
- chemical cleaning steps;
- steps involving relatively high temperatures, typically 300 to 900°C, such as oxide deposition steps, or substantially higher temperatures, typically 1150°C,
30 for thermal oxidation (especially in the case of a silicon carbide SiC wafer);
- steps for implanting one or more gaseous species;
- a wafer bonding step; and
35 - a separation step in which stresses (thermal and/or mechanical and/or other stresses) are applied.

Recycling of the donor wafer requires the successive removal from the latter of thin layers, thereby

progressively decreasing the thickness of the said wafer.

When this donor wafer becomes excessively thin, or else
5 if the starting wafer, before layer removal, is already relatively thin for whatever reason, its use for subsequent removal operations gives rise to the following difficulties:

- there is a high risk of fracture during
10 predominantly mechanical steps, such as the various transfer operations necessary for recycling, bonding by CMP planarization of the surface oxide, etc.;

- there is also a high risk of fracture during
high-temperature heat treatments, especially because of
15 non-uniform temperatures in the wafer;

- simply handling the wafer by an operator also induces a risk of fracture;

- the thinned wafer becomes particularly sensitive to certain technological steps inducing a
20 large strain in the wafer, such as the step of implanting gaseous species or certain deposition steps; typically, in the case of the implantation of gaseous species, the thinned wafer sags significantly, taking on a convex profile; such a sag seriously compromises
25 the moulding operation which requires the contacting surfaces to be of satisfactory flatness.

Thus, there is a minimum donor wafer thickness below which it can no longer be used, or which gives rise to
30 such fractures, to the detriment of the fabrication process, in particular from the economic standpoint.

In particular, in the case of a donor wafer made of SiC, a relatively expensive and fragile material, it
35 turns out that a wafer thinned down to about 200 μm becomes (in the case of wafers with a standard diameter of 2 inches, i.e. about 5 cm) unusable either because fractures during the process become too frequent or because the sag adopted following implantation

precludes proper bonding.

According to another example, there are donor wafers which, at the start, necessarily are of small thickness. Thus, there are at the present time on the market GaN donor wafers thick enough not to pose the aforementioned problems. The current practice is in fact to produce these wafers using the thick epitaxy technique called HPVE (Hybrid Vapour Phase Epitaxy) on an epitaxially grown substrate (seed layer) which is removed after the epitaxy. However, this technique has two major drawbacks: firstly it only makes it possible to obtain self-supporting wafers having a thickness of at most around 200 to 300 μm , since if the intention is to have greater thicknesses, the fact that the lattice matching with the seed substrate is imperfect generates excessive strains; furthermore, and above all, the rate of growth using this technique is extremely low (typically 10 to 100 μm per hour). This is a serious handicap as regards manufacturing cost.

The primary object of the present invention is to alleviate these drawbacks and to provide a process for removing successive thin layers from a donor wafer which can be employed even when the material in which the operations of removing layers from the donor wafer take place reaches extremely small thicknesses.

Thus, according to a first aspect, the present invention provides a process for transferring successive thin layers from a semiconductor material of a donor wafer to a receiving wafer, characterized in that it comprises the following steps:

(a) assembling a bulk slice, consisting of semiconductor material, and a support in order to form a mechanically stable assembly constituting the donor wafer and comprising a donor layer of the said semiconductor material and a support layer;

(b) creating a region of weakness in the donor

layer at a controlled depth;

(c) bonding the donor wafer to the receiving wafer via the free side of the donor layer of the said donor wafer;

5 (d) effecting a separation in the region of weakness of the donor layer, a thin layer of the semiconductor material thus being transferred from the donor wafer to the receiving wafer; and

(e) repeating operations (b) to (d) without the
10 support layer of the donor wafer being breached.

Preferred, but non-limiting, features of the process as defined above are the following:

- step (a) is carried out by wafer bonding
15 between polished faces of the bulk slice and of the support;

- step (a) is carried out by high-temperature welding between polished faces of the bulk slice and of the support;

20 - step (b) is carried out by implanting gaseous species;

- step (c) is carried out by wafer bonding;

- step (d) is carried out by applying stresses, especially thermal and/or mechanical stresses;

25 - steps (a) to (d) are repeated a chosen maximum number of times depending on the thickness of the donor layer and on the depth of the region of weakness;

- the semiconductor material is a single-crystal semiconductor and the support is chosen from the group
30 comprising the same semiconductor as a single crystal of inferior quality, the same semiconductor in polycrystalline form and the same semiconductor as a different polytype;

- the semiconductor material is chosen from the
35 group comprising silicon, silicon carbide and large-gap monometallic or polymetallic nitrides;

- the donor layer has a thickness of around 100 to 300 μm ;

- the support layer has a thickness of around 100

to 300 μm ;

- the semiconductor material is a large-gap monometallic or polymetallic nitride, in particular gallium nitride;

5 - the support layer is a bulk layer and produced from a material taken from the group comprising silicon, gallium nitride, silicon carbide, aluminium nitride and sapphire.

10 Moreover, the conventional technique of producing bulk donor wafers from an ingot typically requires (in the case of single-crystal SiC) the following operating steps:

- cutting the ingot, using a saw, into slices

15 having a thickness of around 1 mm;

- coarsely polishing each of the faces of the slice, in order to remove crystal damaged by sawing and to obtain good planarity; and

- successive polishing of the future front face

20 (the removal face) in order to eliminate work-hardened crystal and to obtain appropriate surface roughness.

Thus, this known process, starting from relatively thick slices, involves substantial losses of material

25 during the successive polishing steps. This obviously affects the manufacturing cost.

Another aspect of the invention is aimed at producing donor wafers with reduced losses, and therefore with

30 more profitable use of the starting material (in this case single-crystal SiC).

According to this second aspect, the present invention therefore provides a process for producing a donor

35 wafer intended to be used in a process for transferring successive thin layers of a given semiconductor material from the said donor wafer to a receiving wafer, characterized in that it comprises the following steps:

(i) producing a bulk slice of the said semiconductor material;

(ii) assembling the said bulk slice and a support in order to form the donor wafer, the latter comprising
5 a donor layer of the semiconductor material and a support layer.

Preferred, but non-limiting, features of the above process are the following:

10 - the bulk slice is produced by sawing an ingot or else by thick-film epitaxy on a seed layer;

- in the latter case, a step of removing the seed layer is provided;

- the process furthermore includes, before step
15 (ii), the following step:

(i') polishing of the bulk slice only on its face intended to come into contact with the support;

- the process furthermore includes, before step (ii), the following step:

20 (i'') polishing, to a defined degree, that face of the bulk slice and that face of the support which are intended to come into contact with each other, and step (ii) is carried out at a temperature and for a time such that wafer bonding or welding is achieved
25 between the bulk slice and the support;

- the semiconductor material is a single-crystal semiconductor and the support is chosen from the group comprising the same semiconductor as a single crystal of inferior quality, the same semiconductor in
30 polycrystalline form and the same semiconductor as a different polytype;

- the semiconductor material is chosen from the group comprising silicon, silicon carbide and large-gap monometallic or polymetallic nitrides;

35 - the semiconductor material is a large-gap monometallic or polymetallic nitride, in particular gallium nitride; and

- the support layer is a bulk layer and produced from a material taken from the group comprising

silicon, gallium nitride, silicon carbide, aluminium nitride and sapphire.

Further features, objects and advantages of the present invention will become more clearly apparent on reading the following detailed description of preferred methods of implementation of the invention, the description being given by way of non-limiting example and with reference to the appended drawings, in which Figures 1a-1e illustrate schematically the steps of a process for transferring thin layers according to the invention.

The process according to the present invention will now be described in its general case.

Before a starting donor wafer is used in a process for removing successive thin layers, this donor wafer is formed by assembling a donor slice and a mechanical support. This assembling operation is preferably carried out by wafer bonding, being performed where appropriate on the donor slice and/or on the mechanical support for the appropriate interface bonding layers.

The mechanical support is chosen so as to be compatible with the treatments imposed by the successive cycles of removing thin layers from the donor slice, especially in terms of temperatures.

In this regard, one important factor is the relationship between the thermal expansion coefficient of the material of the donor slice and that of the material of the mechanical support. Firstly, "homo-assemblies" may be distinguished, that is to say those with materials for the donor layer and for the support layer that have similar chemical and mechanical properties. These will be, for example, layers of the following materials:

- single-crystal SiC (donor) on low-quality

single-crystal or polycrystalline SiC (support);

- single-crystal GaN (donor) on low-quality single-crystal or polycrystalline GaN (support); and

- single-crystal Si (donor) on low-quality single-crystal or polycrystalline Si (support).

In this case, there is practically no limitation as regards thermal budget that can be provided for producing the donor wafer, since the two materials are thermally well matched and the donor layer will be undisturbed by diffusion or the like.

Next, "hetero-assemblies" may be distinguished, those with materials for the donor layer and for the support layer that have different mechanical and/or chemical properties. They will be, for example, layers of the following materials:

- single-crystal SiC (donor) on Si (support);
- indium phosphide InP on Si;
- GaN on Si;
- etc.

In this case, the thermal budget or the temperature to which the assembly may be exposed is more limited because of the thermal mismatch that can result in deformation or fracture. For example, in the case of a donor wafer made of SiC (donor layer) on Si (support layer), difficulties arise with temperatures of around 900 to 950°C being exceeded.

Another important factor is the thickness of the donor slice/support assembly produced, which must be compatible with the steps of the process and make it possible after all to consume as far as possible all or most of the donor slice.

Once the bonding has been carried out and if necessary strengthened by suitable treatments, this assembly becomes a fully-fledged donor wafer, which is handled

during the successive process operations of removing thin layers as if it were a conventional bulk donor wafer, homogeneous throughout its thickness. The number of thin layers removed is chosen essentially according to the thickness of the donor layer and the depth of the region of weakness so that the final removal is effected without the support layer being reached and without any regions of defects, likely to exist at the transition between the donor layer and the support layer, being reached.

If necessary, when the assembling operation has been completed, the donor wafer may be thinned at its rear face (on the support layer side) in order to adjust the thickness of the wafer and make it compatible with the downstream technological steps and with the possible standards. For example, when the support layer is made of silicon, this thinning step can be very easily carried out by mechanical lapping.

Example 1 - SiC case

When the donor slice consists of single-crystal SiC, it is assembled on a support preferably consisting of polycrystalline SiC. The assembling operation may be carried out by direct bonding or else by producing, on the faces to be assembled, intermediate layers made of silicon oxide SiO_2 for example.

In terms of polarity, the SiC single crystal is, for example, bonded to the support on its Si face, whereas the C face of the said single crystal is the exposed face from which thin layers will subsequently be removed, the reverse situation being possible however. It will be seen here that this question of polarity occurs with all materials having a hexagonal crystal structure such as GaN and AlN.

An initial polishing step on this face as well as

intermediate polishing steps between two successive removal operations are preferably carried out.

Because of the fact that the single-crystal SiC of the donor slice and the polycrystalline SiC of the mechanical support both have expansion coefficients close to $4.5 \times 10^{-6}/K$, the assembly thus formed may undergo, without any damage, all the recycling, chemical cleaning, deposition and heat treatment steps associated with the Smart-Cut process for transferring thin layers.

According to a variant, the mechanical support is made of silicon. In this case, compatibility between the support and the donor slice from the thermal standpoint may prove to be inferior, but nevertheless remains satisfactory in particular if the maximum temperatures to which the assembly is subjected during the treatments are limited and, more particularly, if, in order to produce the oxide layers involved in the bonding of the thin layer removed to its support, the oxide is formed by deposition and not by thermal oxidation.

Advantageously, the fabrication of the donor slice/mechanical support assembly involves, again in this example, the following steps:

- a slice is cut from an ingot, with a thickness substantially less than the usual thickness for bulk single-crystal SiC donor wafers, typically with a thickness of around 500 μ m instead of around 1mm conventionally;

- a polishing operation is carried out on only one of the faces of the slice;

- this polished face is brought into intimate contact with a face of suitable planarity of a polycrystalline SiC support wafer so as to bond them together by wafer bonding; the support wafer is

typically produced by thick-film deposition of the CVD type and has a thickness, for example, of 200 to 300 μm ; it should be noted that a low-quality (and therefore inexpensive) single-crystal SiC, or an SiC of a polytype different from that of the donor layer (for example, 6H SiC for the support and 4H SiC for the donor layer), could also be used for the support;

- the assembly is then exposed to a suitable thermal budget (for example 1100°C for 2 hours) in order to obtain suitable bonding forces between the slice and the support wafer; the degree of polishing of the contacting faces should also be taken into account so that satisfactory wafer bonding is obtained under the aforementioned conditions; a single thick single-crystal SiC (donor layer)/polycrystalline SiC (mechanical support layer) combination wafer is thus obtained; as a variant, it would also be possible simply to lay the wafers on top of one another and bond them together by welding (typically at temperatures of 2000°C or higher); however, this is more demanding;

- this combination wafer is then polished on the free face of the single-crystal SiC, with the standard degree of polishing, in order to end up with a single-crystal SiC layer having no buried work-hardened region and having a suitable surface roughness.

This process thus produces donor wafers with very much less loss of expensive material (single-crystal SiC) than the technique mentioned in the introduction of using bulk slices, with furthermore the donor layer and the support being assembled very upstream in the wafer fabrication line, and therefore with no effect on the process of transferring layers from the donor wafer.

The savings achieved are all the greater the more difficult and/or the more expensive it is to produce the SiC ingot (case especially of a semi-insulating SiC ingot of very high purity obtained by the HTCVD (High Temperature Chemical Vapour Deposition) process or of

an SiC ingot having a very low concentration of intrinsic crystal defects such as dislocations and micropipes).

5 Example 2 - the GaN case

In the case of the Smart-Cut technique used with a GaN donor wafer, the various steps employed involve temperatures generally very much lower than those
10 encountered in the case of SiC. Thus, the problem of the respective thermal expansion coefficients of the support and the donor wafer is less crucial. This gives more flexibility in the choice of support material.

15 In the present example, a GaN slice of a thickness of around 100 to 200 μm is wafer bonded to a mechanical support made of polycrystalline or single-crystal SiC for example. As in the case of SiC, the polarity of that face of the GaN wafer which will be on the support
20 side and, consequently, the reverse polarity of that face of the wafer on the free side, that is to say on the side from which layers are removed, are determined in advance.

25 Here again, the support layer/GaN donor layer assembly becomes a fully-fledged wafer used until the donor layer has been completely or almost completely consumed in the various cycles of a Smart-Cut process.

30 The invention is illustrated schematically in Figures 1a to 1e of the drawings.

Illustrated in Figure 1a are a slice 10, of the semiconductor material that will form the successively
35 transferred thin layers, and a support wafer 20.

In Figure 1b, the slice and the support wafer are assembled as described, in order to form the donor wafer 30 comprising the donor layer 10 and the support

layer 20.

5 In Figure 1c, a buried region of weakness 12 is formed at a certain depth from the free surface of the donor layer 10, this region 12 defining a thin layer 101 with respect to the remainder 102 of the donor layer.

10 In Figure 1d, wafer bonding is carried out between the free face of the donor layer 10 (if necessary, with prior oxidation on this face) and one face of a receiving wafer 40 (if necessary, also with prior oxidation on this face).

15 In Figure 1e, a separation is performed, especially by thermal and/or mechanical stress, at the region of weakness 12 in order to obtain, on the one hand, a desired assembly 40, 101, typically forming a substrate for applications in electronics, optoelectronics or optics, and, on the other hand, a donor wafer 30' whose donor layer 10, essentially corresponding to the region
20 102, has been substantially thinned down by the thickness of the thin layer 101 transferred.

25 These steps may be repeated with the donor wafer 30' until the donor layer 10 has been almost entirely consumed, without however broaching the support layer 20.

30 To give a specific example, the steps in Figures 1a and 1b may be carried out on the premises of the donor wafer fabricator, whereas the following steps may form part of a separate process carried out on the premises of the fabricator of composite substrates for the electronics, optoelectronics and optics industries.

35 Of course, the invention applies to the production of wafers comprising donor layers made of other materials, such as aluminium nitride and more generally semiconductor, especially large-gap, monometallic or polymetallic nitrides, diamond, etc., or else single-

crystal silicon of very high quality for the donor layer and low-quality single-crystal or polycrystalline silicon for the support.

CLAIMS

1. Process for transferring successive thin layers from a semiconductor material of a donor wafer to a receiving wafer, characterized in that it comprises the following steps:

(a) assembling a bulk slice, consisting of semiconductor material, and a support in order to form a mechanically stable assembly constituting the donor wafer and comprising a donor layer of the said semiconductor material and a support layer;

(b) creating a region of weakness in the donor layer at a controlled depth;

(c) bonding the donor wafer to the receiving wafer via the free side of the donor layer of the said donor wafer;

(d) effecting a separation in the region of weakness of the donor layer, a thin layer of the semiconductor material thus being transferred from the donor wafer to the receiving wafer; and

(e) repeating operations (b) to (d) without the support layer of the donor wafer being breached.

2. Process according to Claim 1, characterized in that step (a) is carried out by wafer bonding between polished faces of the bulk slice and of the support.

3. Process according to Claim 1, characterized in that step (a) is carried out by high-temperature welding between polished faces of the bulk slice and of the support.

4. Process according to Claim 1, characterized in that step (b) is carried out by implanting gaseous species.

5. Process according to Claim 1, characterized in that step (c) is carried out by wafer bonding.

6. Process according to Claim 1, characterized in that step (d) is carried out by applying stresses, especially thermal and/or mechanical stresses.

5 7. Process according to Claim 1, characterized in that steps (a) to (d) are repeated a chosen maximum number of times depending on the thickness of the donor layer and on the depth of the region of weakness.

10 8. Process according to Claim 1, characterized in that the semiconductor material is a single-crystal semiconductor and the support is chosen from the group comprising the same semiconductor as a single crystal of inferior quality, the same semiconductor in
15 polycrystalline form and the same semiconductor as a different polytype.

9. Process according to Claim 8, characterized in that the semiconductor material is chosen from the
20 group comprising silicon, silicon carbide and large-gap monometallic or polymetallic nitrides.

10. Process according to Claim 9, characterized in that the donor layer has a thickness of around 100 to
25 300 μm .

11. Process according to either of Claims 9 and 10, characterized in that the support layer has a thickness of around 100 to 300 μm .

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12. Process according to Claim 1, characterized in that the semiconductor material is a large-gap monometallic or polymetallic nitride, in particular gallium nitride.

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13. Process according to Claim 12, characterized in that the support layer is a bulk layer and produced from a material taken from the group comprising silicon, gallium nitride, silicon carbide, aluminium

nitride and sapphire.

14. Process for producing a donor wafer intended to be used in a process for transferring successive thin
5 layers of a given semiconductor material from the said donor wafer to a receiving wafer, characterized in that it comprises the following steps:

(i) producing a bulk slice of the said semiconductor material;

10 (ii) assembling the said bulk slice and a support in order to form the donor wafer, the latter comprising a donor layer of the semiconductor material and a support layer.

15 15. Process according to Claim 14, characterized in that the bulk slice is produced by sawing an ingot.

16. Process according to Claim 14, characterized in that the bulk slice is produced by thick-film epitaxy
20 on a seed layer.

17. Process according to Claim 16, characterized in that it includes a step of removing the seed layer.

25 18. Process according to Claim 14, characterized in that it furthermore includes, before step (ii), the following step:

(i') polishing of the bulk slice only on its face intended to come into contact with the support.

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19. Process according to Claim 14, characterized in that it furthermore includes, before step (ii), the following step:

(i'') polishing, to a defined degree, that face of
35 the bulk slice and that face of the support which are intended to come into contact with each other, and in that step (ii) is carried out at a temperature and for a time such that wafer bonding or welding is achieved between the bulk slice and the support.

20. Process according to Claim 14, characterized in that the semiconductor material is a single-crystal semiconductor and in that the support is chosen from the group comprising the same semiconductor as a single crystal of inferior quality, the same semiconductor in polycrystalline form and the same semiconductor as a different polytype.
21. Process according to Claim 20, characterized in that the semiconductor material is chosen from the group comprising silicon, silicon carbide and large-gap monometallic or polymetallic nitrides.
22. Process according to Claim 14, characterized in that the semiconductor material is a large-gap monometallic or polymetallic nitride, in particular gallium nitride.
23. Process according to Claim 22, characterized in that the support layer is a bulk layer and produced from a material taken from the group comprising silicon, gallium nitride, silicon carbide, aluminium nitride and sapphire.