

**PROCESS FOR TRANSFERRING A THIN LAYER ONTO A SUPPORT
SUBSTRATE HAVING DIFFERENT COEFFICIENTS OF THERMAL
EXPANSION**

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FIELD OF THE INVENTION

The present invention relates to the field of heterogeneous structures, combining two substrates which have different coefficients of thermal expansion. More particularly, the invention relates to a process for transferring a thin layer onto a support substrate. This manufacturing process is used, for example, in the fields of microelectronics, micromechanics, photonics, etc.

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TECHNOLOGICAL BACKGROUND OF THE INVENTION

Various processes for forming a thin layer on a support substrate are known from the prior art. Such processes may be, for example, molecular beam epitaxy, plasma sputtering, plasma deposition (laser pulsed deposition) or application of the Smart Cut™ technology in which a thin layer is taken from a bulk substrate by fracturing at a fragile zone (or embrittlement plane) formed in the bulk substrate by implantation of light species.

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The present invention more particularly relates to the formation of a thin layer made of ferroelectric material obtained by applying such a process, as is taught in FR 2 914 492.

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Application of the Smart Cut process is particularly suited to the case where the material of the thin layer that it is desired to transfer has a coefficient of thermal

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expansion similar to that of the support substrate onto which the transfer takes place.

5 In the opposite case, the temperature to which the assembly formed from the support substrate and the donor substrate may be subjected is limited. Thus, FR 2 856 192 recalls that a heat treatment above a temperature determined by the value of the coefficients of thermal expansion of the materials may lead to uncontrolled
10 fracturing of one of the substrates and/or to peeling of the donor substrate or of the thin layer. This poses a problem since the Smart Cut process may make it necessary to perform at least one heat treatment at a sufficient temperature in order, for example, to reinforce the
15 adhesion of the donor substrate to the support substrate, or to facilitate the fracture of the donor substrate on the embrittlement plane.

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OBJECTIVE OF THE INVENTION

One aim of the invention is to propose a process for transferring a thin layer consisting of a first material onto a support substrate consisting of a second material,
25 the first and the second materials having different coefficients of thermal expansion, which at least partly addresses the abovementioned problem. It notably finds its application in transferring a thin layer made of ferroelectric material onto a support having a coefficient
30 of expansion different from that of the material of which this thin layer is composed, for example a support substrate made of silicon.

BRIEF DESCRIPTION OF THE INVENTION

For the purpose of achieving one of these aims, the subject of the invention proposes a process for transferring a thin layer consisting of a first material onto a support substrate consisting of a second material, the first and the second materials having different coefficients of thermal expansion. According to the invention, the process for transferring the thin layer includes the provision of a donor substrate composed of the assembly of a thick layer formed from the first material and from a handling substrate, the coefficient of thermal expansion of the handling substrate being similar to that of the support substrate and the donor substrate having a main face on the thick layer side; the introduction of light species into the thick layer to generate an embrittlement plane therein and to define the thin layer between the embrittlement plane and the main face of the donor substrate; the assembly of the main face of the donor substrate with one face of the support substrate; detachment of the thin layer from the embrittlement plane, the detachment comprising the application of a heat treatment.

The assembly formed from the donor substrate and the support may be exposed to a much higher temperature than that applied in the context of a "direct" approach in accordance with the prior art, according to which the donor substrate does not include any handling substrate, without risk of uncontrolled fracture of one of the substrates or peeling of the donor substrate or of the thin layer. The balanced structure, in terms of coefficient of thermal expansion of this assembly, notably makes it possible to facilitate the step of detachment of the thin layer by exposing the assembly to a relatively high temperature.

According to other advantageous and non-limiting characteristics of the invention, taken alone or in any technically feasible combination:

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- the coefficient of thermal expansion of the first material constituting the thick layer and that of the second material constituting the support substrate differ by at least 10% at room temperature;
- 10 - the difference in coefficient of thermal expansion of the constituent of the handling substrate and of that of the support is less, as an absolute value, than the difference in thermal expansion of the thick layer and of that of the support substrate;
- 15 - the light species implanted are hydrogen ions and/or helium ions;
- the first material is a ferroelectric material such as LiTaO₃, LiNbO₃, LiAlO₃, BaTiO₃, PbZrTiO₃, KNbO₃, BaZrO₃, CaTiO₃, PbTiO₃ or KTaO₃;
- 20 - the material of the support substrate is silicon;
- the handling substrate is of the same nature as the support substrate;
- the handling substrate has a thickness equivalent to that of the support substrate;
- 25 - the thick layer has a thickness of between 10 and 400 micrometres to enable sampling of one or more thin layers;
- the donor substrate is obtained by bonding a source substrate and the handling substrate;
- 30 - the bonding is obtained by molecular adhesion;
- a step of thinning the source substrate is included to provide the thick layer;
- the thinning step is performed by milling and/or mechanochemical polishing and/or etching.

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BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention will
5 become apparent from the following detailed description of
the invention, which description is given with reference to
the appended figures, in which:

- Figures 1A to 1D show an embodiment of a process
10 in accordance with the invention;

- Figure 2 schematically represents a process for
forming a donor substrate in accordance with the invention.

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DETAILED DESCRIPTION OF THE INVENTION

For the sake of keeping the following description
simple, the same references are used for identical elements
20 or for elements performing the same function in the prior
art or in the various presented embodiments of the process.

The figures are schematic representations which, for
the sake of legibility, are not to scale. In particular,
25 the thicknesses of the layers are not to scale with respect
to the lateral dimensions of these layers.

The term "coefficient of thermal expansion" used in
the rest of this description in relation to a layer or a
30 substrate makes reference to the coefficient of expansion
in a defined direction in the main plane defining this
layer or this substrate. If the material is anisotropic,
the coefficient value retained will be that of largest
amplitude. The coefficient value is that measured at room
35 temperature.

The invention relates to a process for transferring a thin layer 3 consisting of a first material onto a support substrate 7 consisting of a second material, the first and the second materials having different coefficients of thermal expansion. The term "different" means that these coefficients differ by at least 10%.

In the context of this description, it will be considered, by way of example, that the thin layer 3 is made of ferroelectric material and the support 7 is made of silicon (the coefficient of thermal expansion of which is estimated as $2.6 \times 10^{-6} \text{ K}^{-1}$).

It is recalled that a ferroelectric material is a material which has an electrical polarization in the natural state, it being possible for this polarization to be reversed by applying an external electric field. The ferroelectric domain refers to each continuous region of the material in which the polarization is uniform (all the dipole moments are aligned parallel to each other in a given direction). A ferroelectric material may thus be characterized as a "monodomain" in the case where this material consists of a single region in which the polarization is uniform or a "multidomain" in the case where the ferroelectric material comprises a plurality of regions having polarities that may be different.

In general, it is generally desirable to have a ferroelectric thin layer of monodomain nature.

With reference to Figure 1A, the donor substrate 1 is composed of a thick layer of ferroelectric material 1a, for example of LiTaO_3 ($2 \times 10^{-6} \text{ K}^{-1}$ (z), $16 \times 10^{-6} \text{ K}^{-1}$ (x, y)), LiNbO_3 , LiAlO_3 , BaTiO_3 , PbZrTiO_3 , KNbO_3 , BaZrO_3 , CaTiO_3 ,

PbTiO₃ or KTaO₃ and of a handling substrate 1b. The donor substrate 1 may take the form of a circular wafer of standardized size, for example of 150 mm or 200 mm in diameter. However, the invention is not in any way limited to these dimensions or to this form. The thick layer of material 1a may have been sampled from an ingot of ferroelectric material, this sampling having been performed so that the thick layer 1a has a predetermined crystalline orientation. The orientation is chosen as a function of the intended application. Thus, it is common practice to choose an orientation 42° RY in the case where it is desired to exploit the properties of the thin layer to form an SAW filter. However, the invention is not in any way limited to a particular crystalline orientation.

The handling substrate 1b advantageously consists of a material (or of a plurality of materials) giving it a coefficient of thermal expansion close to that of which the support substrate 7 is composed. The term "close" means that the difference in coefficient of thermal expansion of the handling substrate 1b and of that of the support 7 is less, as an absolute value, than the difference in thermal expansion of the thick layer 1a and of that of the support substrate 7.

Preferentially, the handling substrate 1b and the support substrate have an identical coefficient of thermal expansion. During the assembly of the donor substrate and of the support, a structure is formed that is capable of withstanding a heat treatment at a relatively high temperature. For the sake of ease of implementation, this may be obtained by selecting the handling substrate 1b so that it consists of the same material as that of the support substrate 7.

To form the donor substrate 1, a bulk block of ferroelectric material is preassembled with the handling substrate 1b, for example by means of a molecular adhesive bonding technique. Next, the layer of ferroelectric material 1a is formed by thinning, for example by milling and/or mechanochemical polishing and/or etching. This process is presented schematically in Figure 2. Before assembling, the formation of an adhesion layer (for example by deposition of silicon oxide and/or silicon nitride) onto one and/or another of the faces placed in contact may have been envisaged. The assembling may comprise the application of a low-temperature heat treatment (for example between 50 and 300°C, typically 100°C) making it possible to strengthen the bonding energy sufficiently to allow the following step of thinning.

The handling substrate 1b may be chosen to have a thickness substantially equivalent to that of the support substrate 7. The thinning step is performed such that the thick layer 1a has a thickness that is small enough for the stresses generated during the heat treatments applied in the rest of the process to be of reduced intensity. At the same time, this thickness is large enough to be able to sample the thin layer 3 or a plurality of such layers therefrom. This thickness may be, for example, between 5 and 400 microns.

The process comprises the introduction into the donor substrate 1 of at least one light species. This introduction may correspond to an implantation, i.e. ion bombardment of the main face 4 of the donor substrate 1 with light species such as hydrogen and/or helium ions.

In a manner known per se, and as is represented in Figure 1B, the implanted ions have the role of forming an

embrittlement plane 2 delimiting a thin layer 3 of ferroelectric material to be transferred which is located on the main face 4 side and another part 5 constituting the rest of the substrate.

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The nature, the dose of the implanted species and the implantation energy are chosen as a function of the thickness of the layer that it is desired to transfer and of the physicochemical properties of the donor substrate. In the case of a donor substrate 1 made of LiTaO_3 , it may thus be chosen to implant a dose of hydrogen of between 1^{E16} and 5^{E17} at/cm^2 with an energy of between 30 and 300 keV to delimit a thin layer 3 of the order of 200 to 2000 nm.

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In a following step, represented in Figure 1C, the main face 4 of the donor substrate 1 is assembled with one face 6 of a support substrate 7. The support substrate 7 may have the same dimensions and the same shape as those of the donor substrate. For reasons of availability and cost, the support substrate 7 is a monocrystalline or polycrystalline silicon wafer. However, more generally, the support substrate 7 may consist of any material, for example silicon, sapphire or glass, and may have any shape.

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Prior to this step, it may be envisaged to prepare the faces of the substrates to be assembled via a step of cleaning, brushing, drying, polishing or plasma activation.

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The assembling step may correspond to placing the donor substrate 1 in intimate contact with the support substrate 7 by molecular adhesion and/or electrostatic bonding. Optionally, to facilitate the assembling of the two substrates 1, 7 notably when they are assembled by direct bonding, at least one intermediate layer may be

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formed prior to the assembling, either on the main face 4 of the donor substrate 1, or on the flat face 6 to be assembled of the support substrate 7, or on both. This intermediate layer consists, for example, of silicon oxide, silicon nitride or polycrystalline silicon and has a thickness of between a few nanometres and a few microns. The intermediate layer may be produced according to the various techniques known in the prior art, such as oxidation or nitridation heat treatments, chemical depositions (PECVD, LPCVD, etc.), etc.

On conclusion of this assembling step, the assembly represented in Figure 1C is obtained, comprising the two associated substrates, the flat face 6 of the support substrate 7 adhering to the main face 4 of the donor substrate 1.

The assembly is then treated to detach the thin layer 3 of ferroelectric material from the donor substrate 1, for example by cleavage on the embrittlement plane 2.

This detachment step may thus comprise the application to the assembly of a heat treatment in a temperature range of the order of 80°C to 500°C to allow the transfer of the thin layer 3 onto the support substrate 7. In addition to the heat treatment, this step may comprise the application of a blade or jet of gaseous or liquid fluid to the embrittlement plane 2. In the case of a ferroelectric material, care will be taken not to exceed its Curie temperature, so as not to deteriorate the characteristics of the thin layer.

Following this detachment step, the structure 9 represented in Figure 1D is obtained. This structure 9 comprises the thin layer 3 of ferroelectric material

comprising a first free face 8 and its main face 4 arranged on the support substrate 7.

5 The assembly formed from the donor substrate 1 and the support 7 may be exposed to a much higher temperature than that applied in the context of a "direct" approach in accordance with the prior art, according to which the donor substrate does not include any handling substrate, without risk of uncontrolled fracture of one of the substrates or
10 peeling of the donor substrate 1 or of the thin layer 3. The balanced structure, in terms of coefficient of thermal expansion of this assembly, thus makes it possible to facilitate the step of detachment of the thin layer 3 by exposing the assembly to a relatively high temperature, for
15 example of between 80°C and 500°C.

It is then possible to perform a step of finishing of the thin layer 3 and notably of its free face 8 in order to restore and/or improve the desired properties of this thin
20 layer. As is well known per se, this finishing may comprise polishing, etching, sacrificial oxidation, or annealing under a neutral or reductive or oxidizing atmosphere.

In the context of the example that has just been
25 presented, and in which the thin layer 3 is made of ferroelectric material, this finishing step may correspond to a heat treatment of the thin layer 3 followed by polishing, this sequence making it possible to restore the initial monodomain properties which the thick layer 1a had,
30 for example following an orientation of 42°RY, on the thin layer 3 after transfer. However, the invention is not in any way limited to a particular finishing sequence.

The heat treatment makes it possible to correct
35 crystalline defects present in the thin layer 3. In

addition, it contributes towards consolidating the bonding between the thin layer 3 and the support 7. The heat treatment brings the structure to a temperature of between 300°C and the Curie temperature of the ferroelectric material for a time of between 10 seconds and 10 hours. This heat treatment is preferentially performed by exposing the free face of the thin layer 3 to an oxidizing or neutral gaseous atmosphere.

The preparation process also includes, after the heat treatment, thinning of the thin layer 3. This thinning may correspond to polishing of the first free face 8 of the thin layer 3, for example by means of mechanical, mechanochemical and/or chemical etching thinning techniques. It makes it possible to prepare the free face 8 so that it has little roughness, for example less than 0.5 nm RMS 5×5 μm by atomic force measurement (AFM) and to remove a surface part of the first free face 8 of the thin layer 3 that is liable to contain residual defects.

Needless to say, the invention is not limited to the example described and embodiment variants may be made thereto without departing from the scope of the invention as defined by the claims.

Furthermore, the invention applies to any "heterogeneous" structure in which differences in coefficient of thermal expansion exist between the thin layer 3 and the support substrate 7, for instance in the case of a silicon on quartz or silicon on sapphire structure.

CLAIMS

1. Process for transferring a thin layer (3) consisting of a first material onto a support substrate (7) consisting of a second material, the first and the second materials having different coefficients of thermal expansion, the process being characterized in that it includes:
 - a. the provision of a donor substrate (1) composed of the assembly of a thick layer formed from the first material (1a) and from a handling substrate (1b), the coefficient of thermal expansion of the handling substrate (1b) being similar to that of the support substrate (7) and the donor substrate (1) having a main face (4) on the thick layer (1a) side;
 - b. the introduction of light species into the thick layer (1a) to generate therein an embrittlement plane (2) and to define the thin layer (3) between the embrittlement plane (2) and the main face (4) of the donor substrate (1);
 - c. assembling the main face (4) of the donor substrate with one face (6) of the support substrate (7);
 - d. detaching the thin layer (3) from the embrittlement plane (2), the detachment comprising the application of a heat treatment.
2. Process according to the preceding claim, in which the coefficient of thermal expansion of the first material constituting the thick layer (1a) and that of the second material constituting the support substrate (7) differ by at least 10% at room temperature.
3. Process according to either of the preceding claims, in which the difference in coefficient of thermal expansion of the constituent of the handling substrate (1b) and of that of the support (7) is less, as an absolute value, than the difference in thermal expansion of the thick layer (1a) and of that of the support substrate (7).

4. Process according to one of the preceding claims, in which the implanted light species are hydrogen and/or helium ions.
- 5 5. Process according to one of the preceding claims, in which the first material is a ferroelectric material such as LiTaO₃, LiNbO₃, LiAlO₃, BaTiO₃, PbZrTiO₃, KNbO₃, BaZrO₃, CaTiO₃, PbTiO₃ or KTaO₃.
- 10 6. Process according to one of the preceding claims, in which the material of the support substrate (7) is silicon.
- 15 7. Process according to one of the preceding claims, in which the handling substrate (1b) is of the same nature as the support substrate (7).
- 20 8. Process according to one of the preceding claims, in which the handling substrate (1b) has a thickness equivalent to that of the support substrate (7).
- 25 9. Process according to one of the preceding claims, in which the thick layer (1a) has a thickness of between 10 and 400 micrometres to enable sampling of one or more thin layers.
- 30 10. Process according to one of the preceding claims, in which the donor substrate (1) is obtained by bonding of a source substrate (10) and of the handling substrate (1b).
11. Process according to the preceding claim, in which the bonding is obtained by molecular adhesion.
- 35 12. Process according to one of the two preceding claims, comprising a step of thinning of the source substrate (10) to provide the thick layer (1a).

13. Process according to the preceding claim, in which the thinning step is performed by milling and/or mechanochemical polishing and/or etching.