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Use of an electric field for detaching a piezoelectric layer from a donor substrate

10 The invention relates to a method for transferring a piezoelectric layer onto a support substrate. It also relates to a detaching chamber for carrying out at least a part of the method.

There is raising interest in compound structures comprising a support substrate, like Silicon
15 or Sapphire, with a thin piezoelectric layer attached thereto. It has been proposed to use a SmartCut™ type process, known from Silicon on Insulator substrates, to obtain such a compound structure.

The process could make use of a piezoelectric donor substrate with a predetermined splitting
20 area inside the donor substrate. The predetermined splitting area can be obtained by implanting ions into the donor substrate. The donor substrate is subsequently attached to the support substrate and undergoes a thermal treatment to strengthen the bond between the donor and the support substrate and to detach the remainder of the donor substrate at the predetermined splitting area to thereby transfer a layer of the piezoelectric donor substrate
25 onto the support substrate.

Under the effect of the higher temperature during the thermal treatment, the defaults created
in the predetermined splitting area by the implanted ions grow leading to local strain which at
a given thermal budget leads to the detachment and thereby to the layer transfer onto the
30 support substrate.

In case of a piezoelectric donor substrate, it is, however, difficult to transfer the layer without
breakage. This is due to the large difference in thermal expansion coefficients between the
piezoelectric donor substrate and the support substrate (CTE mismatch). Thus, strain
35 develops during the heat treatment at the interface of the donor and support substrate which suddenly relaxes at the moment of detachment and leads to the breakage of the transferred layer.

It is therefore the object of the present invention to provide an alternative layer transferring method which is particularly important to reduce breakage of the transferred piezoelectric layer due to CTE mismatch.

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This object is achieved with the method of transferring a piezoelectric layer onto a support substrate according to the invention and which comprises the steps of: a) providing a predetermined splitting area in a piezoelectric donor substrate, b) attaching the piezoelectric donor substrate to a support substrate to form a compound, and c) detaching the piezoelectric layer from the piezoelectric donor substrate comprising applying an electric field. By applying an electric field use is made of the piezoelectric properties of the donor substrate to weaken the predetermined splitting area, as the electric field will introduce a deformation within the piezoelectric donor substrate and further weaken the area of the defaults in the predetermined splitting area due to building up complementary strain. As a consequence, the thermal budget necessary for the complete detachment of the piezoelectric layer to be detached can be lower.

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According to certain embodiments, the piezoelectric donor substrate may be made of a single piezoelectric material, a so-called bulk piezoelectric substrate. According to other embodiments, the piezoelectric donor substrate may be made of a layer of piezoelectric material provided on a handle substrate. In the second case, a handle substrate may be chosen with a similar CTE with respect to the support substrate. A difference in CTE between handle and support substrate that is lower than 10%, with respect to the larger of the two CTE, allows a higher thermal budget for the thermal treatments assisting the above described method compared to higher differences in the CTE and/or compared to the use of bulk piezoelectric substrates with a higher CTE difference with respect to the support substrate.

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According to an embodiment, the method can further comprise an ion implantation step to form the predetermined splitting area and a thermal treatment step of the ion implanted piezoelectric donor substrate wherein the thermal treatment step can be carried out in a temperature range of 0°C to 200°C for a duration between 1h to 24h. The thermal treatment step thereby may allow the defects in the predetermined splitting area to grow.

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According to a preferred variant, step b) can comprise a heat treatment with a temperature of at most 100°C or at most 50°C or in a variant can be carried out at room temperature in

between 15°C to 25°C. In a manufacturing process in which the detachment is achieved by a thermal treatment only, the bonding interface needs to be stabilized prior to the detachment step to prevent unwanted bonding defects at the moment of detachment. In the prior art, the enhancement of the bonding is obtained by heating the compound prior to detachment. As
5 already mentioned above such a heat treatment leads to problems related to the difference in thermal expansion coefficient in case of a piezoelectric donor substrate. By using an electric field during the detachment, the bonding energy between the donor substrate and the support substrate can be lower compared to the bonding energy necessary for a thermally induced detachment only. This due to the fact that the impact of the mechanical distortion
10 due to the presence of the electric field is very much limited to the piezoelectric donor substrate and has a lower impact on the interface with the support substrate.

According to a preferred variant, step b) can be carried out at a pressure below 10^{-2} mbar.

15 Preferably, step c) can be carried out at a temperature of less than 100°C, more in particular less than 50°C, even more in particular at room temperature in between 15°C to 25°C. Thus, the detachment can be obtained at lower temperature compared to a detachment process that is not assisted by an electric field.

20 According to a preferred embodiment, the electric field can be applied using a chuck comprising at least one electrode. By using such chuck, the electric field can be made available in a simple manner. The chuck may comprise holding means which are independent of such electrodes and being implemented by for instance vacuum or electrostatic properties.

25 Advantageously, the surface of the piezoelectric donor substrate of the compound can be placed onto the chuck. In this arrangement, the process can be carried out independently of the electric properties of the support substrate.

30 According to a variant, the chuck can comprise interdigitated electrodes separated by an electric isolator, in particular a ceramic. In this geometry it is possible to create a suitable electric field using only one electrode. This keeps the design of the processing chamber simple.

35 According to an embodiment, the voltage applied to the chuck can be of up to 10kV, in particular in a range between 1kV and 5kV. In this voltage range a sufficiently strong electric

field is formed in order to deform the piezoelectric donor substrate such that detachment can occur at a lower thermal budget.

According to a variant, the donor substrate - support substrate compound can be sandwiched between the chuck and a second electrode, in particular being comprised in a second chuck. In a design using an electrode on both sides of the compound, the voltage applied to the first and second electrodes can be lower than in case of only one electrode.

Preferably, in this variant of the invention, the voltage applied to the electrostatic chuck can be of up to 5kV, in particular in a range between 200V and 1kV.

According to an embodiment, the electric field lines can be essentially parallel to the polarization direction of the piezoelectric donor substrate. By aligning the electric field to the polarization direction of the piezoelectric donor substrate the amplitude of the resulting distortion can be enhanced and the detachment step facilitated.

Preferably, the piezoelectric donor substrate can be one of LiTaO_3 (LTO), AlN , ZnO , $\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$ ($0 \leq x \leq 1$) (PZT) and LiNbO_3 (LNO). Preferably, the support substrate can be a semiconductor substrate, in particular a Si wafer, or an isolator, in particular a sapphire wafer, or a metal, in particular a Mo wafer.

The object of the invention is also achieved with a detaching chamber for carrying out step c) as described above and which comprises one or two chucks for applying an electric field to a piezoelectric layer. The detaching chamber could, according to a variant, also be used for carrying out step b). The use of the chuck allows the creation of an electrical field which leads to a deformation in the piezoelectric substrate thereby weakening the predetermined splitting area. As a consequence the thermal budget necessary to perform the detachment of the piezoelectric layer from the remainder of the donor substrate can be lower compared to a process using only the thermal energy for the detachment step. Thus, the negative impact of a large difference in the thermal expansion coefficient between the donor substrate and the support substrate can be reduced.

The object of the invention is also achieved with a chuck that comprises holding means for holding the compound, in particular vacuum and/or electrostatic holding means and electrodes for applying an electric field for weakening a predetermined splitting area inside the compound. According to a variant, the electrostatic holding means and the electrodes for

applying the electrical field can be independent from each other. In this way, the holding action and the weakening action as described above with respect to the method can be optimized with respect to each other.

- 5 The present invention will be explained more in detail hereafter using advantageous exemplary embodiments in conjunction with the accompanying figures, wherein:

Figures 1a to 1e schematically illustrate an embodiment of the method of transferring a piezoelectric layer onto a support substrate,

- 10 Figure 2 schematically illustrates a setup according to a second embodiment of the invention,

Figure 3 schematically illustrates a setup according to a third embodiment of the invention.

- 15 Figures 1a to 1e illustrate an embodiment of the method of transferring a piezoelectric layer onto a support substrate.

In the process step illustrated in Figure 1a, corresponding to step a) of the method according to the invention, a predetermined splitting area 1 is created in a piezoelectric donor substrate

- 20 3 by implanting ions 5.

The piezoelectric donor substrate 3 can e.g. be LiTaO_3 (LTO), AlN , ZnO , $\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$ ($0 \leq x \leq 1$) (PZT) and LiNbO_3 (LNO). In the following, as an example according to the invention only, the piezoelectric donor substrate is a bulk piezoelectric substrate made of LTO.

- 25 According to a variant, the donor substrate could comprise a handle substrate with a piezoelectric layer on top of it.

To obtain the predetermined splitting area 1 inside the piezoelectric donor substrate $3 \cdot 5 \cdot 10^{16}$ to $2 \cdot 10^{17}$ H^+ or He^+ or a mix of H^+/He^+ ions/ cm^2 are implanted with an energy of about 10keV to 1 MeV as a function of the desired depth d of the predetermined splitting area 1. Under the

- 30 implanting conditions mentioned above, the depth d is of the order of 60nm to 6 μm .

The next step, illustrated in Figure 1b, is a first thermal treatment step to let the defects 7 forming the predetermined splitting area 1 created by the ion implantation, grow. The

- 35 roughness of the surface 9 is below 5nm RMS. According to the invention, this first thermal

treatment step is carried out at temperatures between 0°C and 200°C for a duration of about 1 to 24hrs.

Step b) according to the invention is illustrated in Figure 1c. It consists in attaching, in particular by bonding, the piezoelectric donor substrate 3 to a support substrate 11 to thereby form a compound 13. The support substrate 11 can be semiconductor substrate, like a Si wafer, or an isolator, like sapphire, or a metal, like Mo.

The bonding step is carried out at ambient pressure or under vacuum, typically a primary vacuum of below 10^{-2} mbar, in particular of the order of 10^{-3} to 10^{-4} mbar. In order to strengthen the bonding between the two substrates 3 and 11, the bonding is carried out at a temperature of up to 100°C.

Figure 1d illustrates the next step in the manufacturing process. This step corresponds to step c) according to the invention. An electric field is applied to the compound 13, with the electric field lines 15 essentially perpendicular to the predetermined splitting area 1.

According to an aspect of the invention, the electric field lines 15 are essentially parallel to the polarization axis 17 (or poling axis) of the piezoelectric donor substrate 3 to optimize the piezoelectric effect. Due to the piezoelectric properties, the presence of the electric field 15 will lead to a mechanical deformation in the direction z inside the piezoelectric support substrate 3. This deformation further weakens the predetermined splitting area 1. To obtain the desired electric field, voltages of up to 10kV are applied (see description further down with respect to figures 2 and 3).

Depending on the strength of the electric field, a complete detachment of the remainder 19 of the piezoelectric donor substrate from the modified compound 13' comprising the support substrate 11 and a transferred piezoelectric layer 21 can occur at the predetermined splitting area as illustrated in Figure 1e.

According to a variant, the detachment as shown in Figure 1e can also be obtained by heating the compound 13 during or after the application of the electric field 15. In this second heat treatment step, temperatures of up to 100°C are used for the final detachment. The choice of the temperature depends on the conditions of first heat treatment step and the strength of the electric field 15.

With the method according to the invention, it becomes possible to transfer thin piezoelectric layers 21 onto a support substrate 11 without suffering from an existing large difference in the thermal expansion coefficient between the material of the piezoelectric layer 21 and the support substrate 11.

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The remainder 19 of the piezoelectric donor substrate can then be reused as a donor substrate 3 to restart the process as described with respect to Figures 1a to 1e.

Figure 2 schematically illustrates a setup according to a second embodiment of the invention.

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Figure 2 shows a detaching chamber 31 used to carry out at least step c) of the method according to the invention as illustrated in Figure 1d.

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The detaching chamber comprises a chuck 33 comprising positive electrodes 35 and negative electrodes 37 to be able to apply an electric field 39 to the compound 13 comprising the piezoelectric donor substrate 3 and the support substrate 11 as described in detail with respect to the first embodiment. The description of the features of the first embodiment will not be repeated again, but is incorporated herewith by reference. The chuck may comprise further means for holding the compound 13, e.g. vacuum or electrostatic means. In this embodiment, those are independent of the electrodes 35 and 37.

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The compound 13 is positioned on the chuck 33 such that the piezoelectric donor substrate 3 of the compound 13 is placed onto the chuck 33.

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The positive and negative electrodes 35, 37 are arranged such that the electric field 39 is essentially perpendicular to the surface of the chuck 33 at least within the thickness d' of the piezoelectric donor substrate 3. With the polarization axis 17 of the piezoelectric donor substrate also being perpendicular to the chuck 33, the piezoelectric effect can be optimized thereby creating mechanical strain in the predetermined splitting area 1 further leading to weakening.

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According to a variant, it could also be the support substrate that is positioned on the chuck 33, especially in case the electric field is strong enough. However, for an isolating support substrate 11, it is preferable to position the piezoelectric donor substrate 3 on the chuck 33.

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In one variant, the positive electrodes 35 and negative electrodes 37 are interdigitated with an electric isolator (not shown), e.g. a thin ceramic layer, positioned in between.

The control unit of the splitting chamber 31 is configured such that electric tensions of up to 10kV can be applied to the electrodes, preferably, 1kV to 5kV. In this embodiment only one electrostatic chuck is necessary which simplifies the design of the detaching chamber 31.

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Figure 3 schematically illustrates a setup according to a third embodiment of the invention. Figure 3 shows a second embodiment of a detaching chamber 51 used to carry out at least step c) of the method according to the invention as illustrated in Figure 1d. The description of the features of the first and second embodiment will not be repeated again, but is

10 incorporated herewith by reference.

In this embodiment, two chucks 53 and 55 are used. The lower chuck 53 comprises a positive electrode 57; the upper chuck 55 comprises a negative electrode 59. According to a variant, the polarization can be exchanged. The compound 13 is sandwiched between the

15 two chucks 53, 55.

Also in this configuration, the electric field lines 61 are parallel to the polarization direction 17 of the piezoelectric donor substrate to optimize the piezoelectric effect leading to optimized weakening in the predetermined splitting area 1.

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In this electrode configuration, voltages of up to 5kV, especially 200V to 1kV, can be applied to the electrodes 53, 55 to obtain the desired effect in the predetermined splitting area 1 without observing a detachment at the interface between the piezoelectric donor substrate 3 and the support substrate 11.

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The detaching chamber 31, 51 of the second and third embodiment may, according to further variants, be used for step b) of the method according to the invention, thus to realize the attachment step as illustrated in Figure 1c. Furthermore it may, according to additional variants, also comprise heating means and/or a vacuum pump to be able to carry out the

30 heat treatments and/or carry out the process steps under vacuum.

Features of any one of the first to third embodiment can be combined individually or in groups with any one of the other embodiments to form further variants of the method and/or splitting chamber according to the invention.

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Claims

1. Method of transferring a piezoelectric layer onto a support substrate comprising the steps of:
 - a) providing a predetermined splitting area (1) in a piezoelectric donor substrate (3),
 - b) attaching the piezoelectric donor substrate (3) to a support substrate (11) to form a compound (13), and
 - c) detaching the piezoelectric layer (21) from the piezoelectric donor substrate (3) comprising applying an electric field (15).
2. Method according to claim 1, wherein the piezoelectric donor substrate is made of a bulk piezoelectric substrate.
3. Method according to claim 1, wherein the piezoelectric donor substrate is made of a layer of piezoelectric material provided on a handle substrate.
4. Method according to one of claims 1 to 3, wherein step b) comprises a heat treatment with a temperature of at most 100°C, in particular of at most 50°C, or is carried out at room temperature in between 15°C to 25°C.
5. Method according to one of claims 1 to 4, wherein step b) is carried out at a pressure below 10^{-2} mbar.
6. Method according to one of claims 1 to 5, wherein step c) is carried out at a temperature of less than 100°C, more in particular less than 50°C, even more in particular at room temperature in between 15°C to 25°C.
7. Method according to one of claims 1 to 6, wherein the electric field (15) is applied using a chuck comprising at least one electrode.
8. Method according to claim 7, wherein the surface of the piezoelectric donor substrate of the compound is placed onto the chuck.
9. Method according to claim 8, wherein the chuck comprises interdigitated electrodes separated by an electric isolator, in particular a ceramic.

10. Method according to claim 9, wherein the voltage applied to the chuck is of up to 10kV, in particular in a range between 1kV and 5kV.

11. Method according to claim 7 or 8, wherein the compound is sandwiched between the chuck and a second electrode, in particular being comprised in a second chuck.

12. Method according to claim 11, wherein the voltage applied to the electrostatic chuck is of up to 5kV, in particular in a range between 200V and 1kV.

13. Method according to one of claims 1 to 12, wherein the electric field lines (15) are essentially parallel to the polarization direction (17) of the piezoelectric donor substrate (3).

14. Method according to one of claims 1 to 13, wherein the piezoelectric donor substrate (3) is one of LiTaO_3 (LTO), AlN , ZnO , $\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$ ($0 \leq x \leq 1$) (PZT) and LiNbO_3 (LNO).

15. Method according to one of claims 1 to 14, wherein the support substrate (11) is a semiconductor substrate, in particular a Si wafer, or an isolator, in particular a sapphire wafer, or a metal, in particular a Mo wafer.

16. Detaching chamber for carrying out step c) according to one of claims 1 to 15 comprising one or two chucks comprising first and/or second electrodes for applying an electric field to a piezoelectric layer.

17. Detaching chamber according to claim 16, wherein at least one of the chucks comprises holding means, in particular vacuum and/or electrostatic holding means.

18. Detaching chamber according to claim 17, wherein the first and/or second electrodes are independent of the electrostatic holding means.