# METHOD FOR IMPROVING THE QUALITY OF A TAKEN THIN LAYER

## FIELD OF THE INVENTION

The invention relates to a method of forming a structure comprising a layer taken off from a semi-conductor material from a donor wafer, the method comprising the following successive steps:

(a) implanting atomic species to form a weakness zone in the donor wafer at a given depth;

(b) bonding the donor wafer to a host wafer;

(c) supplying energy so as to detach the layer taken off from the donor wafer at the weakness zone;

(d) treating the taken off layer.

## BACKGROUND OF THE INVENTION

This type of layer taking-off is called Smart-Cut® and is known to those skilled in the art. In particular, details may be found in many documents that have already been published, such as for example the extract on pages 50 and 51 of the work "Silicon on Insulator technology: material tools VLSI, second edition," by Jean-Pierre Colinge published by "Kluwer Academic Publishers".

Step (a) may be carried out by simple implantation (for example of hydrogen) or by co-implantation (for example hydrogen and helium) with dosing of the chemical types to be implanted and suitable implantation energy.

Step (b) of the bonding of the host wafer (of the layer taken-off) typically takes place on the surface of the donor wafer having undergone the implantation, by means of a bonding layer made of dielectric material such as $SiO_2$.

The bonding techniques typically used by those skilled in the art include initial bonding by molecular adhesion. We can refer to the document "Semiconductor Wafer Bonding Science and Technology" (QY Tong and U.

Gösele, Wiley Interscience Publication, Johnson Wiley and Sons, Inc.) to obtain more information.

In step (c), the energy is at least partially provided, typically in the form of heat. It is therefore the thermal budget (the temperature/ duration of the heat treatment combination) that needs to be considered to determine the moment when the layer to be detached will be detached.

In this way, a semiconductor on insulator structure may be formed, such as an SOI structure (in the case of the detached layer being made of silicon), SiGeOI (in the case of the detached layer being made of germanium silicon), sSOI (in the case of the taken-off layer being made of strained silicon), SGOI (in the case of the taken-off layer comprising a relaxed SiGe layer on which lies a strained Si layer) or GeOI (in the case of the detached layer being made of germanium).

It can be frequently observed that after detachment of the detached layer, the latter may have quite a rough surface, as well a lower quality crystalline structure on its surface, due especially to the fact that the implantation and the detachment steps have taken place beforehand.

In reference to figure 1, a semiconductor on insulator structure 30 is shown diagrammatically (composed of a host wafer 20 covered by the detached layer 1 by means of an electrically isolating layer 5), which has, in its semiconductor part (i.e. the detached layer 1), such a reduction in the crystalline quality.

It may be observed that the detached layer 1 comprises a defective zone 1A, this defective zone 1A comprising existing crystalline defects and surface roughness.

The defective zone 1A typically has a thickness of around 150 nm for an atomic implantation of hydrogen.

Furthermore, the implantation step may have caused a reduction in the crystalline quality in the layer to be detached 1.

Step (d) of the treatment of the detached layer 1 is therefore necessary to remove this defective zone 1A, and thus recuperate at least part of the sound zone 1B of the layer taken 1.

For example, it is possible to use mechanical polishing or chemical-mechanical polishing (CMP) to eliminate the surface roughness, and/or sacrificial oxidation steps of the defective zone 1A.

By way of illustration, such a four steps method is described in the document US2004/0053477, in which a strained silicon layer is detached from a donor substrate comprising a SiGe buffer layer. Step (a) consists of making the implantation in the buffer layer, and step (d) comprises the removal of the part detached from the buffer layer by means of surface polishing the SiGe then selective etching of the SiGe with respect to the strained Si. The selective etching permits in particular to obtain finally the desired layer with a good quality of surface finish, without too high a risk of damaging it (which could be the case if only polishing were used).

However, the chemical etching used in this step (d) may in certain cases lead to at least partial detachment problems of the bonding interface (bonding carried out in step (b). Indeed, the chemical etching of step (d) may in particular cause de-lamination at the edge of the bonding layer, which is to say attack the latter where it touches by the slice of the structure created. For example, we can mention the case of a HF treatment on an sSOI (strained Silicon on Insulator) structure comprising $SiO_2$, buried under the strained Si, or the case of a $H_2O_2$:HF:HAc treatment (HAc being the abbreviation of acetic acid) on an sSi/SiGeOI structure (strained silicon on SiGe On Insulator), where the buried SiGe and $SiO_2$ layers are likely to be etched under the strained Si layer.

An alternative that could be envisaged to overcome the last problem would be to dilute the etching solution considerably so that its action is easier to control. However this solution is not satisfactory due to the fact that it does not totally resolve the de-lamination problem and that the method is slightly slowed down.

Moreover, this chemical etching requires prior preparation of the surface to be etched, typically carried out using mechanical polishing means. In fact, this etching preparation remains necessary to correct part of the major roughness which could subsequently lead to etching that is not

sufficiently homogeneous and likely to create traversing defects or holes in the remaining layer.

Whereas successive actions of polishing and chemical etching make the post-detachment finishing step (d) (as well as the entire sampling method) long, complex and costly from an economic point of view.

It is further mentioned that it has also been proposed to perform the step (a) of implanting by implanting several atomic species (typically by performing an implantation of helium and an implantation of hydrogen). This type of implantation is hereafter designated by the term of co-implantation.

Performing a co-implantation indeed allows for a total dose of co-implanted species to be used lower than when a single species is implanted. The total dose in co-implantation thus typically represents 1/3 of the dose in single species implantation.

It results from this decrease in total implanted dose a decrease of the defective zone thickness which in particular allows to reduce or to simplify the finishing treatments performed after detachment.

However, as it has been shown by the Applicant in its PCT application filed on September 21, 2004 under n° IB2004003300 (and not yet published), and which teaching has been made available to the public online on the IP.com site on March, 1 2005 under reference IPCOM000083333D, in relation to co-implantation within a Si layer, the co-implantation parameters that help minimizing roughness lead to the formation of certain defects (such as blisters at the bonding interface, or crystalline defects within the thickness of the taken-off layer), and reciprocally the co-implantation parameters that help minimizing said defects lead to increased roughness. In other words, a compromise has to be made between roughness and formation of these defects, and the recourse to co-implantation thus does not allow as such to satisfactorily solve the above mentioned problems relating to the presence of defects and a superficial roughness.

A first purpose of the invention is to reduce the duration, the economic cost and the number of treatment means during step (d), of a taken-off layer, and in particular to stop using mechanical polishing means.

A second purpose of the invention is to avoid the delamination of the edge of the bonding layer when the finishing chemical etching takes place.

A third purpose of the invention is to create a structure, such as a semiconductor on insulator structure, comprising a taken-off layer including a more weakness material than Si, such as strained Si or SiGe.

A fourth purpose is to make such a structure from a sampled layer of better quality

A fifth purpose of the invention is to reduce the quantity of material wasted when treating the taken-off layer.

A sixth purpose of the invention is to propose a simple method of treating the taken-off layer that can easily be incorporated into the entire sampling Smart-Cut® type method.

## SUMMARY OF THE INVENTION

This invention attempts to overcome these problems by proposing according to a first aspect, a method of forming a structure comprising a layer that is taken-off from a donor wafer, the donor wafer comprising prior to taking-off a first layer made of a first material chosen among semiconductor materials and a second layer on the first layer made of a second material chosen among semiconductor materials, the method comprising the following steps:

(a) implanting atomic species to form a weakness zone under the second layer;

(b) bonding the donor wafer to a host wafer;

(c) supplying energy so as to disunite the taken-off layers from the donor wafer at the weakness zone;

(d) selective etching of the remaining part of the first layer with respect to the second layer;

wherein the parameters of the implantation carried out in step (a) are adjusted so as to minimise the surface roughness which appears immediately after carrying out step (c), and wherein the method comprises

moreover a step capable of strengthening the bonding, carried out at a temperature less than about 800°C (1,472°F).

Other possible characteristics of the invention are:

- a step capable of strengthening the bond is carried out prior to step (b), and comprises plasma activation;

- a step capable of strengthening the bonding is carried out after step (b), and comprises plasma heat treatment;

- another step capable of strengthening the bonding is carried out after step (b), and comprises plasma heat treatment;

- the heat treatment is carried out at a temperature of between around 350°C (660°F) and around 800°C (1,472°F), for between about 30 minutes and around 4 hours;

- the heat treatment is carried out at a temperature of between around 550°C (1,022°F) and around 800°C (1,472°F), for between about 30 minutes and around 4 hours;

- the heat treatment is carried out after step (c) and in continuity from step (c) in a same furnace;

- the heat treatment comprises a single temperature change as from the separation temperature of step (c) to the temperature chosen for the heat treatment;

- step (c) is carried out at around 500°C (1,022°F) for a duration that can last up from about 30 minutes to around 2 hours;

- the step capable of strengthening the bonding is carried out so that prior to step (d), an energy greater than or equal to around 0.8 J/m² is obtained;

- the said surface roughness which appears immediately after the step (c) are less than approximately 40ÅRMS measured on a surface of 10 x 10µm;

- the atomic species implanted during step (a) comprise distinct atomic elements, step (a) thus being a co-implantation;

- the co-implantation of step (a) is a co-implantation of helium and hydrogen;

- the donor wafer comprising a SiGe layer, the co-implantation of step (a) is performed under implantation parameters adapted to form the weakness zone within said SiGe layer and for the helium concentration peak to be located, within the thickness of the donor substrate, more in depth than the hydrogen spreading zone and also more in depth than the weakness zone ;

- the thermal treatment is performed at a temperature substantially comprised between 575°C and 625°C ;

- the dosing of helium and hydrogen are chosen as respectively being around $0.9.10^{16}/cm^2$ and $1.0.10^{16}/cm^2$;

- after step (c), the method does not comprise mechanical polishing means;

- the method comprises moreover, after step (d), a crystalline growth of the second material on the second layer to make the latter thicker;

- the first layer is made of $Si_{1-x}Ge_x$ where $0<x\leq1$ and the second layer is made of elastically strained Si;

- the donor wafer comprises a support substrate made of solid Si, a buffer structure made of SiGe, a first layer comprising $Si_{1-x}Ge_x$ ($x \neq 0$) and a second layer made of strained Si;

- the first layer is made of elastically strained SiGe and the second layer made of $Si_{1-x}Ge_x$ with $0<x\leq1$, the donor wafer comprising moreover a third layer made of $Si_{1-x}Ge_x$ under the first layer;

- the implantation of step (a) is also carried out under the first layer and the method comprises moreover between step (c) and step (d), selective etching of the remaining part of the third layer with respect to the first layer;

- the donor wafer comprises a support substrate made of solid Si, a buffer structure made of SiGe, and a multi-layer structure alternatively comprising first layers of $Si_{1-x}Ge_x$ ($x \neq 0$) and second layers made of strained Si, so as to be able to take off several times from a same donor wafer;

- the method further comprises, prior to step (a), the formation of the strained layer at a deposit temperature of between around 450°C (842°F) and around 650°C (1,202°F), and the treatments used between this deposit

and the detachment obtained at step (c)are carried out at temperatures less than or equal to the deposit temperature;

- the method further comprises, prior to step (b), a step of forming a bonding layer on the donor wafer and/or on the host wafer, the bonding layer comprising an electrically insulating material, for example such as $SiO_2$, $Si_3N_4$ or $Si_xO_yN_z$.

According to a second aspect, the invention proposes an application of the said method of forming a structure, for the formation of a semiconductor-on-insulator structure.

According to a third aspect, the invention proposes a semiconductor on insulator structure obtained after carrying out all of the steps (a), (b) and (c) of the method, and after removing the contact of the taken off layers with the remaining part of the donor wafer, this structure having a surface roughness of less than about 40ÅRMS measured on a surface of 10 × 10µm, and a bonding energy greater than or equal to around 0.8 J/m².

## BRIEF DESCRIPTION OF THE FIGURES

Other characteristics, aims and advantages of the invention will become clear upon reading the following detailed description of the application of preferred methods of it, given by way of non-restrictive examples and made in reference to the appended diagrams in which:

Figure 1 shows a diagrammatical cross section of a semiconductor on insulator structure obtained after the application of a Smart-Cut® method according to the state of the technique.

Figure 2 shows a cross sectional view obtained by TEM by the applicant of a semiconductor on insulator structure obtained after application of the method of the invention.

Figures 3a to 3e show diagrammatically the different steps of a method of the invention to form a structure comprising a layer taken using Smart-Cut®.

Figure 4 shows a first time evolution of the heat treatment temperatures that may be used according to the invention, during the

separation step and during the treatment of the taken-off layer according to the method shown in figures 3a to 3e.

Figure 5 shows a second time evolution of the heat treatment temperatures that may be used according to the invention, during the separation step and during the treatment of the taken-off layer according to the method shown in figures 3a to 3e.

Figures 6a and 6b show diagrammatically a first variant according to the invention.

Figures 7a and 7b show diagrammatically a second variant according to the invention.

Figures 8a, 8b and 8c represent cross sectional views obtained by TEM of a Si donor wafer having been subjected to a He/H co-implantation.

Figures 9 10 and 11 present surface roughness measurements notably on structures respectively including a taken-off layer comprising Si and SiGe.

Figure 12 notably presents defects quantification results for structures including a taken-off layer comprising respectively Si and SiGe.

DETAILED DESCRIPTION OF THE INVENTION

Examples of embodiments of methods according to the invention are described below, as well as applications according to the invention, based on layers taking-off using Smart-Cut® in type IV materials or alloys, and in particular in Si and SiGe.

In reference to figures 3a to 3e, is shown a first method of taking-off a first layer 1 in $Si_{1-x}Ge_x$ (where $x \in [0;1]$) and a second layer 2 of elastically strained Si from a donor wafer 10, to transfer them to a host wafer 20 according to the invention.

In reference to figure 3a, a donor wafer 10, comprising the first layer 1 made of $Si_{1-x}Ge_x$ and the second layer 2 of elastically strained Si, is illustrated.

Classically, a donor wafer 10 including $Si_{1-x}Ge_x$ comprises a solid Si substrate 5 on which has been formed for example by crystalline growth a buffer structure of SiGe (not shown) made up of different layers. In particular,

the latter may have a gradual evolution in thickness in its composition of Ge, starting from 0% at the solid Si substrate level to around 100x% at the level of the interface with the first layer 1 made of $Si_{1-x}Ge_x$ (it also preferably being formed by crystalline growth).

A second layer 2 of strained Si is formed on the first layer 1 in $Si_{1-x}Ge_x$. In a first case, the growth of the second layer 2 is carried out in situ, directly in continuation of the formation of the first layer 1. In a second case, the growth of the second layer 2 is carried out after a light step of preparation of the surface of the underlying adaptation layer 2, for example by CMP polishing.

The second layer 2 made of Si is advantageously formed by epitaxy using known techniques such as Chemical Vapour Deposition (CVD) and Molecular Beam Epitaxy (MBE) techniques.

The silicon contained in the second layer 2 is then obliged by the first layer 1 to increase its nominal mesh parameter to make it more or less identical to that of its growth substrate and thus to present internal elastic strain tensions. It is necessary to form a quite thin second layer 2: if the layer is too thick, thicker than a critical equilibrium thickness, would cause a relaxation of the strain in the film thickness towards the nominal lattice parameter of the silicon and/or generation of faults. We can refer to the document entitled "High mobility Si and Ge structures" by Friedrich Schaffler ("Semiconductor Science Technology", 12 (1997) 1515-1549) for more details on this subject.

However, in the particular case of a deposit of strained material at a sufficiently low temperature, it may become possible to form such a second strained layer 2 with a greater thickness (the critical balance thickness is indeed linked to the deposit temperature: it is all the more important as the deposit is realized at low temperature).

In reference to figure 3b, a weakness zone 4 is then formed in the donor wafer 10 underneath the second layer 2. In particular, this implantation may be made in the first layer 1 made of $Si_{1-x}Ge_x$ (not shown in figure 3b).

This weakness zone 4 is formed by implantation of atomic species whose dosage, nature and energy are chosen so that a depth of implantation and a level of fragility are determined.

In particular, the parameters determining the implantation of atomic types are adjusted so as to minimise the surface roughness which appears at the level of the weakness zone 4 after detachment. In fact, the extent of the post-detachment surface roughness is partially caused by the parameters defining the implantation used, as we will subsequently see.

Thus, preferably according to the invention, the implantation of atomic species may be a co-implantation of atomic species (i.e. the implantation of, principally, at least two atomic elements), such as for example a co-implantation of hydrogen, helium or argon or another rare gas or another suitable gas.

In the case of a co-implantation, the applicant has in fact observed that the weakness zone 4 is generally thinner than in the case of a simple implantation (see study below).

The energy of the implantation is chosen so as to have an implantation depth neighbouring that of the depth of the first layer 1.

Thus for a co-implantation with helium of around $0.9.10^{16}/cm^2$ and energy of between 50 and 90 kev and hydrogen at $1.0.10^{16}/cm^2$ and energy of between 20 and 60 kev, we can obtain a depth of implantation of around 300 to 600 nanometres.

One finds here one of the advantages of co-implantation which allows for the taking-off of a thin layer using a total dose of co-implanted species lower than the dose to be used when a single species is implanted. The total dose in co-implantation thus typically represents 1/3 of the single species implantation dose.

The recourse to a co-implantation will above all allows obtaining a post-detachment surface roughness lower than the roughness obtained with a simple hydrogen or helium implantation. This surface roughness is thus typically less than around 40ÅRMS measured on a surface area of 10 x $10\mu m^2$.

In reference to figure 3c, a bonding step of a host wafer 20 with the side of the donor wafer 10 having undergone the co-implantation is carried out.

The host wafer 20 may be made of solid Si or other materials.

Prior to the implantation step, a bonding layer may be formed, such as a layer comprising $SiO_2$, $Si_3N_4$, $Si_xO_yN_z$ on one and/or the other of the respective surfaces to be bonded. In the case of this bonding layer has to be formed on the donor wafer, the technique used to form this bonding layer may be a deposit, in order to avoid any deterioration of the strains in the second layer 2 or any diffusion consequently in the first layer 1.

Prior to bringing the host wafer 20 into contact with the donor wafer 10, the surfaces to be bonded may possibly be prepared, using known surface cleaning and polishing techniques such as SC1 and SC2 solutions, ozone solutions etc.

The bonding itself may be firstly carried out by molecular adhesion, by being able to take account of the hydrophily of each of the two surfaces to be bonded.

It is also possible to use plasma activation of one or both of the two bonding surfaces just before bonding.

A plasma activation permits in particular to create handling bonds, for example on an oxide surface, on the surface(s) to be treated, and therefore increase the bonding forces to be made and reduce the number of defects at the bonding interface 6, as well as their influence on the quality of the bonding.

Such strengthening of the bonding interface 6 will also have the advantage of therefore making this interface much more resistant to chemical attacks from later etching (used when finishing the surface of the layer taken off) and avoid delamination problems at the edges as previously discussed, which may typically appear for a bonding energy below approximately 0.8 $J/m^2$.

In particular, the plasma activation is used so that in the end, after bonding and after taking-off, the bonding energy is greater than or equal to approximately 0.8 J/m².

The plasma may be obtained for example from an inert gas, such as Ar or $N_2$, or from an oxidising gas such as $O_2$.

The plasma activation is typically carried out at ambient temperature, below approximately 100°C. The use of this technique therefore also has the advantage of not causing any notable problems of diffusing Ge from the first SiGe layer 1 to the second strained Si layer (generally speaking, the diffusion of Ge starts to become significant in the thickness of the neighbouring layers for much higher temperatures, typically around 800°C or more).

The duration of the plasma treatment is very quick, typically less than one minute.

The equipment used will be for example standard plasma etching equipment of the RIE or ICP-RIE types or other.

After using such a treatment prior to bonding, an annealing heat treatment of less than 800°C or less than a limit temperature from which we can consider that the diffusion of Ge in the neighbouring layers becomes damaging, may be used later at bonding, to strengthen the bonding further in order to avoid further still any delamination when carrying out the post-detachment selective etching, contrary to the heat treatments without prior plasma activation which demand, for an equivalent result, temperatures greater than approximately 900°C to be efficient and which cannot be used in this case in particular due to the problems of Ge diffusion.

We can therefore typically reach a bonding energy of at least 1 J/m² after an annealing heat treatment at 200°C, in the case of bonding being preceded by plasma activation.

In reference to figure 3d, is shown the separation step. This is carried out by providing heat energy and/or mechanical energy, sufficient to break weak links at the weakness zone 4, and thus disunite the donor wafer 10 into a first part 10' comprising a remainder of the first layer 1" and into a second part 30 comprising the other part of the first layer 1' and the second layer 2.

This heat energy may then be sufficient to cause, at the weakness zone 4 level, thermal effects on the gaseous types enclosed there causing the rupture of weak links.

Disuniting may be obtained at temperatures of between around 300°C and around 600°C for durations of varying lengths which depend on whether the temperature is lower (longer) or higher (longer).

We can use, for example, for a layer to be taken-off made of $Si_{1-x}Ge_x$, heat treatment at a temperature of around 500°C for a duration that can range from 15 to 30 minutes up to 2 hours.

In the case of disuniting being carried out solely by heat treatment, this may allow the disuniting to occur without necessarily ending the contact with the remaining part of the donor wafer 10'.

In this last case, and optionally, we can carry out a new heat treatment method directly after the separation, without removing the wafers from the furnace (in which the separation heat treatment method took place), and without creating any additional handling which would be a waste of time and would require the use of appropriate equipment. Moreover, the remaining part of the donor wafer 10' offers protection to the first and second taken-off layers 1' and 2' against any possible contaminants, oxidants or other such agents, which offers the possibility of again using the heat treatment in various atmospheres.

A heat treatment could also be carried out after the wafers have been physically separated (and removed from the detachment furnace).

In this way, according to a variant of the method, we can use a heat treatment to strengthen the bonding interface 6 directly after separation.

This heat treatment may be used in addition or in replacement of the plasma activation that may possibly be used before bonding (see above).

In the case of this heat treatment being used in addition to the plasma activation, it is therefore possible to make sure that the combined effects of these two treatments achieve the desired objectives, an in particular a bonding energy sufficient to make the bonding interface 6 resistant to chemical attack from later etching, and thus to avoid delamination problems

on the edges, as previously described. We can thus combine the two treatments to strengthen the bonding interface 6 to obtain a bonding energy greater than or equal to approximately 0.8 J/m².

In any case, the heat treatment for strengthening the bonding interface 6 is carried out at a temperature $T_2$ chosen below the temperature above which Ge diffuses significantly into the thickness of the second layer 2.

This heat treatment is chosen so as to strengthen the bonding sufficiently to prevent any risk of delamination at the edges during the selective etching that will be used after the taking-off. In particular, this heat treatment may be used so as to obtain as a result a bonding energy higher than or equal to approximately 0.8 J/m².

The heat treatment to strengthen the bonding interface 6 is carried out at a temperature $T_2$ lower than or equal to approximately 800°C.

In the case of the remaining part 10' of the donor wafer and the structure 30 still being in contact after disuniting, this heat treatment to strengthen the bonding interface 6 is carried out at a temperature lower than the re-adhesion temperature from which the two parts 1' and 1" of the first layer re-adhere (or join together again), the re-adhesion temperature being considered here, within the scope of the invention, and based on the experience of the applicant on SiGe, of over approximately 800°C.

Optionally, the temperature $T_2$ is greater than the temperature $T_1$ to which the wafers 10 and 20 were subjected when disunited.

This heat treatment to strengthen the bonding is carried out in an inert atmosphere (such as an Ar or $N_2$ atmosphere) that is oxidising or slightly oxidising.

The temperature $T_2$ may for example be situated between 350°C and 800°C, maintained for between 30 minutes and 4 hours.

The temperature $T_2$ may even more particularly be situated between 550°C and 800°C, maintained for between about 30 minutes and 4 hours.

In reference to figures 4 and 5, are provided examples of possible temperature evolutions according to the invention during joining phases and strengthening of the bonding interface 6.

Thus, in reference to figure 4, a first platform of around 500°C is reached and maintained for around 30 minutes in order to create at the end a disuniting (at the level of the arrow 1000), then an increase in temperature to approximately 600°C to carry out a heat treatment to strengthen the bonding interface 6 according to the invention (at the level of the temperature platform 2000). This bonding interface 6 strengthening heat treatment may then last for 2 hours or more.

In reference to figure 5, the separation does not occur during a temperature platform but during a temperature increase around 500°C (at the level of the arrow 1000 in the figure) then the bonding interface 6 strengthening temperature platform 2000 is reached at around 600°C.

Surprisingly, the applicant has thus observed that by using such a step of bonding interface 6 strengthening, in particular when it is followed by a co-implantation step, the taken off layers then have:

- an improved crystalline quality in their parts damaged during the implantation (in reference to figure 3b) and during disuniting (in reference to figure 3d);
- a smoothed surface, in particular for high frequency roughness (HF roughness);
- a bonding energy greater than approximately 0.8 J/m² (without plasma activation).

After removal of the remaining part of the donor wafer 10' from its contact with the taken-off layers 1' and 2, a structure 30 is obtained comprising the host wafer 20, the second layer 2 and the remaining part of the first layer 1'. This structure 30 has an improved crystalline quality and reduced roughness, without having need for an intermediate polishing operation.

In the case of an electrically insulating layer being formed beforehand, between the second layer 2 and the host wafer 20, then a SiGe/sSOI or Ge/sSOI structure is obtained.

A finishing step is then used to remove the slight roughness and few remaining crystalline defects at the surface, such as the use of chemical etching.

The mechanical polishing means used prior to the chemical etching to reduce the surface roughness (and therefore to make the different points of the etching more homogeneous), do not necessarily need to be included. In fact, as we will see below, the co-implantation used ensures a much smoother sampling surface than hat obtained by simple implantation.

Furthermore, the bonding strengthening heat treatment allows this roughness to be substantially diminished, as described above, and to increase the bonding energy.

The $Si_{1-x}Ge_x$ layer 1' may possibly be removed in order to obtain a final sSOI structure. It is then possible to make the strained silicon of this structure thicker by epitaxy.

To remove the layer 1' of $Si_{1-x}Ge_x$ selectively, it is possible to use selective etching by using for example $HF:H_2O_2:CH_3COOH$, SC1 ($NH_4OH/H_2O_2/H_2O$) or HNA ($HF/HNO_3/H_2O$).

A selectivity of around 40:1 between the SiGe and the sSi may be obtained with $CH_3COOH/H_2O_2/HF$.

An example of concentration that may be chosen for the $CH_3COOH/H_2O_2/HF$ is such that the ratio $H_2O_2/HF$ is comprise between 1/1 (very concentrated) and 20/1.

The length of the etching is directly correlated with the speed of etching. It is typically around 5 minutes for 800A to be etched with $CH_3COOH/H_2O_2/HF$.

Thus, the co-implantation and the possible use of bonding strengthening heat treatment having considerably reduced the surface roughness and the non-uniformities of thickness in the taken-off layers 1' and 2, it is possible to use more or less the same selective etchings as those of the state of the technique, but by also eliminating the disadvantages that they can present, such as the need to use beforehand mechanical polishing means.

Moreover the bonding strengthening (carried out by plasma activation and/or post-separation heat treatment) is sufficient to eliminate the problems of delamination at the edges mentioned earlier.

In reference to figure 2, a structure 30 SiGeOI of 20% Ge (photographed by TEM) obtained by the applicant following a transfer of a single layer of $Si_{0.8}Ge_{0.2}$ in which the weakness zone has been created, and following a post-disuniting heat treatment at 600°C, shows a taken-off layer 1 in $Si_{0.8}Ge_{0.2}$ (i.e. the equivalent of the said first layer 1 and second layer 2 together, previously discussed in reference to figures 3a to 3e) covers a layer of $SiO_2$ 5 and comprises very few crystalline defects and very little roughness with respect to the semiconductor on insulator structure of figure 1.

In particular, it can be noted the disproportion between the thickness of the defective zone 1A of the taken-off layer 1 in reference to figure 1 and that of the remedied taken-off layer 1 in reference to figure 2.

Similarly, and for a same thickness of taken-off layers 1 for figure 1 and for figure 2, the sound zone 1B is much greater proportionally in the SiGeOI obtained according to the invention than in the semiconductor-on-insulator according to the prior art.

Moreover, results of surface roughness measurements made on such a SiGeOI structure with 20% Ge, carried out by the applicant, are presented in the table below. These measurements were made just after separation at 500°C for about 30 minutes following simple implantations or co-implantations, and at a bonding strengthening heat treatment (post separation) at 500°C or 600°C.

The roughness was measured and the values are given in RMS or peak to valley (PV) by AFM on surface areas of 10 x 10 µm.

It should be noted that the applicant has carried out a sufficient number of measurements to validate the results.

| Nature of the implantation | Bonding strengthening treatment | Surface roughness | |
|---|---|---|---|
| | | RMS (Å) | PV (Å) |

| | | | |
|---|---|---|---|
| Simple implantation<br>H: 40keV-6.$10^{16}$/cm² | 500°C/30 min | 80 – 85 | 850 |
| | 600°C/30 min | 38 | 420 |
| Co- implantation of H and He:<br>H: 35keV-1.0.$10^{16}$/cm²<br>He: 70keV-0.9.$10^{16}$/cm² | 500°C/30 min | 49 | 407 |
| | 600°C/30 min | 33 | 272 |

In this table, it can be noted that the surface roughness is less significant in the case of a co-implantation than in the case of a simple implantation.

Thus, the applicant has highlighted the influence of the nature of the implantation made in SiGe to form a weakness zone 4, on the extent of the post-disuniting roughness which appears: a helium – hydrogen co-implantation permits the roughness of the SiGe layer 1 to be substantially reduced with respect to a simple hydrogen implantation.

In this table, it can also be noted that, in all cases (implantation of a single species or co-implantation of several species) a recovering operation at 600°C reduces by almost a third both the mean (RMS) and maximum (PV) roughnesses with respect to a recovering operation at the disuniting temperature (approximately 500°C), the roughnesses being less than 40 Å RMS, and even less than 35 Å RMS for co-implantation cases, and below below 275 Å PV.

The applicant has thus established that there is significantly less roughness when the taken-off layer 1 has undergone a post-separation bonding strengthening heat treatment.

In reference to figure 3e, a sSOI structure 30 is finally obtained.

In the case of one or more bonding layers being buried under the bonding interface 6, a heat treatment may possibly then be used to strengthen the bonding further, in particular by creating covalent links.

This bonding strengthening heat treatment may be carried out here at a temperature of over 800°C, given that there is no more SiGe or Ge in the

structure 30, and that there are therefore no more problems of diffusion of Ge (the remainder of the first layer 1' having been completely removed).

Possibly, a subsequent step pf crystalline growth may be used (for example MBE or CVD epitaxy) to thicken the second layer of strained Si.

Other roughness measurements on a sSI structure (for which a strained Si layer has been deposited on a SiGe layer comprising 20% of Ge) made by the Applicant are presented hereafter. These results more particularly concern certain detachment parameters, and notably several co-implantation parameters.

One reminds hereunder different problems encountered when forming a structure comprising a Si layer taken off from a donor wafer according to a taken off process of the Smart-Cut®type. These problems (and a solution to cure them) have been discussed in the Applicant's PCT application already mentioned above, and which teaching have been made available to the public on March, 1 2005 under reference IPCOM000083333D.

The recourse to a co-implantation can indeed lead to the formation of blisters at the bonding interface and of defects within the thickness of the taken off layer.

Particles or organic substances present on one and/or the other of the wafers to be bonded can prevent the bonding to be carried out in a satisfying manner at certain regions of the bonding interface. The implanted species may then diffuse to the weakly bonded bonding interface regions, forming blisters at the level of the bonding interface.

Furthermore, locally, the bonding energy may not be sufficient to allow the detachment of the donor wafer. Certain zones of the taken off layer may then not be transferred onto the host wafer (these zones are communally designated under the term of "non transferred zones" or ZNT).

In addition, crystalline defects of the nano-cavities type (presenting a diameter of some nanometers) may be observed, depending upon the chosen co-implantation conditions, within the thickness of the taken off layer, beyond the defective zone. These defects may result from an agglomeration of Silicium or Germanium atoms displaced during implantation. In particular,

when helium is implanted sensibly at the same depth than hydrogen, these nano-cavities type defects (located beyond the defective zone, but as much undesirable than the defects present in the defective zone) are observed within the thickness of the taken off layer. The appearance of these defects necessitates the removal after detachment of a thickness of material more important than necessary, and thus necessitates the taking off of a thicker layer.

In reference to the views of figures 8a, 8b et 8c obtained by TEM, a co-implantation of helium and hydrogen in a Si donor wafer for the taken off of a layer following a thermal detachment treatment is represented.

Figure 8a represents a view obtained by TEM pthotography of a Si donor wafer having been subjected (see arrows) to a co-implantation of helium and hydrogen. The distribution of these species in the thickness of the donor wafer is perceptible (see dark points) on this figure 8a.

After bonding to a host wafer, a thermal treatment leads to the disunion at the level of the weakness zone (see figure 8b). Figure 8c represents (in reversed sight compared to figure 2) the taken-off layer after detachment and transfer onto a host wafer. On this figure 8c, one can notice the defective zone close to the surface, as well as the presence of defects (dark points) in the thickness of the taken-off layer.

Each of the implanted species is distributed, within the thickness of the donor wafer, according to a repartition profile having a spreading zone within which the species is mainly concentrated and presenting a maximum concentration peak. More precisely, the repartition has a quasi-Gaussian profile presenting a standard deviation (defining said spreading zone wherein the species is mainly distributed, for instance within which one finds 70% of the implanted species) and a maximum concentration peak which notably depend upon the implantation energy.

The helium atoms diffuse within the Si matrix more easily than the hydrogen atoms. Hence if helium is implanted close to the bonding interface, the risk increases that blisters or crystalline defects beyond the defective zone form. A way to cure this problem consists in implanting helium more in

depth than hydrogen, so that the hydrogen containing region may block the diffusion of helium. It is more precisely a question of controlling the co-implantation parameters so that the helium peak is located more in depth than the hydrogen spreading zone.

However, it has been shown that the roughness after detachment does not follow the same tendency, and tends to increase when helium is implanted more deeply than hydrogen. This signifies that the implantation conditions (i.e. implantation doses and energies) do not allow to independently controlling the roughness and the formation of blisters and crystalline defects beyond the defective zone. It is thus necessary to make a compromise between the best parameters for limitation of the formation of blisters and defects and the best parameters for limitation of the surface roughness.

A solution making it possible to overcome this problem has already proposed by the Applicant in PCT application already mentioned previously and which teaching was made available to the public on March 1, 2005. Generally speaking, this solution consists in precisely controlling the relative position of the hydrogen and helium peaks in the implanted donor wafer (the helium peak being located at the level of the embrittlement zone and more in-depth than the hydrogen spreading zone), and in jointly controlling the dose of each species (the helium dose accounting for approximately 40% to 60% of the total amount). By carrying out the step of implantation by co-implanting according to these parameters, a satisfactory compromise can be found between roughness and formation of defects.

The experiments carried out by the Applicant on the detachment at the level of layers containing Ge (typically layers of SiGe comprising more than 15% Ge) led to surprising results with regard to the roughness and the formation of blisters and crystalline defects beyond the defective zone.

A possible embodiment of the process according to the present invention is as follows:

- to carry out a co-implantation, typically of helium and hydrogen, in a layer of SiGe, according to implantation parameters adapted to shift the

concentration peaks of helium and hydrogen, in particular so that the helium peak is located more in-depth than the hydrogen spreading zone, but also so that the helium peak is located more in-depth than the embrittlement zone

- and to implement a post disunion recovering heat treatment at a temperature about 600°C (+/- 25 °C), to be maintained from 30 minutes up to four hours, for example during approximately an hour.

Typically, the implantation parameters are adapted "to place" the helium peak at a depth approximately 1,2 times higher than the depth of the hydrogen peak. As an example, for the conditions of implantation dose and energy presented in the present application, this means placing the helium peak at more than 500 angströms from the hydrogen peak.

The helium dose lies between 30% and 70% of the total dose (hydrogen + helium), preferably ranging between 40% and 60% of the total dose. The total dose typically represents some $10^{16}$atomes/cm², without that being restrictive.

Such an embodiment makes it possible to strongly reduce roughnesses (in particular those of high frequencies), and makes in addition low roughnesses independent from the helium implantation depth. It is thus possible, within the framework of this embodiment, to implant helium more deeply than hydrogen, which makes it possible to limit the formation of blisters and crystalline defects beyond the defective zone in the taken-off layer, the diffusion of helium in the transferred layer being blocked by the hydrogen spreading zone.

Consequently, this embodiment makes it possible to minimize at the same time the roughness post detachment, the number of defects of the blisters type and the number of defects found in the thickness of the taken-off layer. This results in authorizing the taking-off of a lower total thickness, which makes it possible to reduce, or all at least to simplify, the post-detachment finishing operations (polishing, selective etching, sacrificial oxidation, etc).

Figures 9 to 11 represent measurements of roughness post-detachment on a SOI structure and a SGOI structure (at 20% of Ge).

These measurements were carried out just after disunion following simple implantations of hydrogen only (indicated by Honly on these figures) or He/H co-implantations (indicated by CoI on these figures), and a recovering treatment of one hour, at 500°C or 600°C.

More precisely, the change of the temperature at the time of the operations of disunion and bonding strengthening was as follows: maintenance of a stage at 350°C during approximately an hour, then rise in temperature according to a slope of 5°C/mn, then maintenance of a stage (to strengthen the bonding) respectively at 500°C and 600°C during approximately an hour.

Figures 9 and 10 thus represent measurements of roughness at high frequencies carried out by sweeping respectively a surface area of 2*2µm² and a surface area of 10*10µm² using a AFM microscope. Figure 11 represents measurements of roughness at low frequencies carried out by profilometry using the Dektak® tool of Veeco Instruments Inc company.

On each one of these figures 9 to 11, one has represented results of roughness measurement expressed on the left in average values (RMS) and on the right in maximum values (statement).

On these figures, one has showed the result of measurement carried out following implantation in a layer of Si, and in a layer of SiGe (see figure 9 on which columns relative respectively to Si and in SiGe are clearly distinguished).

As concerns Si, two wafers, subjected to a He/H co-implantation, were studied. The co-implantation parameters were as follows:

H: 30kev-$1.10^{16}$/cm²

He: 52 or 60 keV - $1.010^{16}$/cm²

As concerns SiGe, five wafers were studied, namely a wafer subjected to an implantation of H only (H: 30 keV, $6.10^{16}$/cm²), and four others subjected to a He/H co-implantation according to the following parameters:

H: 30 keV - $1.10^{16}$/cm²

He: 48, 52, 56 or 60 keV - $1.10^{16}/cm^2$

Figure 9 confirms the very interesting profit in term of high frequencies roughnesses related to the He/H co-implantation in comparison with H alone (and that that it is following à recovering treatment at 500°C or at 600°C).

It is observed however that for a high temperature treatment at 600°C, roughness strongly decreases (typically of more than half) for all the alternatives, including implantation of H alone. And these values of roughness are even weaker when a co-implantation is carried out.

In addition, one observes, that for a 500°C treatment (in a way similar to what was observed in Si) roughness tends to increase when the helium peak is located more in-depth than the embrittlement zone.

On the other hand, within the framework of a high temperature treatment at 600°C, roughness is sensibly not modified when one implants helium such that the helium peak is located more deeply than the embrittlement zone. One observes here an unexpected behaviour, in opposition against what was observed in Silicon, as well as in SiGe with a 500°C treatment.

The results presented on figures 10 and 11 confirm these observations.

The behavior in co-implantation, during a recovering treatment at 600°C, is surprising insofar as the phenomenon noted up to now by the Applicant within the framework of a detachment on the level of a layer of Si were that of an increase in roughness when the helium implantation energy was increased (helium peak shifted more in-depth than the embrittlement zone).

The phenomenon of post-detachment surfaces smoothing is thus related not only to the temperature of the recovering treatment, but also to the types of materials present in the donor wafer. In the experiments carried out, the difference lies in the presence of Ge in a wafer in SiGe, a Si wafer being obviously deprived of Ge.

In reference to figure 12, the Applicant also carried out measurements aiming at noting the number of defects (ZNT type, blisters) present in the various transferred layers.

The macroscopic observation (in grazing light) makes it possible to detect the defects of the ZNT type or blisters. One regards here the sum of these defects (ZNT + blisters) as being representative of the specific defects related to the implantation and observed post-detachment.

A significant number of defects is noted in the two alternatives He: 48keV and He:52keV, i.e. the alternatives for which the helium distribution profile is superimposed or quasi superimposed with the hydrogen profile (the helium peak being then "inside" the hydrogen spreading zone).

On the other hand, a low number of defects is noted in the alternatives He: 56 keV and He: 60 keV, i.e. the alternatives for which the helium peak is located more in-depth than the hydrogen spreading zone. In other words, the defects of the blisters type are minimized when helium is deeply implanted (and that, in the case of a recovering operation at 600°C, without roughness being increased).

According to a second variant of the invention, in reference to figures 6a and 6b, the donor wafer 10 comprises prior to taking off a first layer 1 of strained Si, then a second layer 2 of $Si_{1-x}Ge_x$ and a third layer 3 of $Si_{1-x}Ge_x$ that is situated underneath the first layer 1. The weakness zone is then formed according to the invention under the second layer 2, for example in the third layer 3. Selective etching of the $Si_{1-x}Ge_x$ may then be used after separation in compliance with what has been already seen, so as to create finally a SGOI structure 30 (Strained Silicon On Insulator structure, as shown in figure 6b) with a first layer 1 of strained Si and a second layer 2 of $Si_{1-x}Ge_x$.

Optionally and alternatively, a second selective chemical etching of the strained Si may be carried out, for example by means of chemical types based for example on KOH (potassium hydroxide), $NH_4OH$ (ammonium hydroxide), TMAH (tetramethyl ammonium hydroxide) or EDP (ethylene diamine / pyrocathecol / pyrazine). In this case, the first layer 1 made of strained Si only plays the role of a stop layer protecting the second $Si_{1-x}Ge_x$

layer 2 from the first chemical attack. A SiGeOI structure 30 (not shown) is then obtained. A layer of strained Si can be possibly grown on the SiGeOI, this new strained layer may then have a better quality crystalline structure than the first layer 1 which has previously been etched.

According to a third variant of the invention, in reference to figures 7a and 7b, the donor wafer 10 comprises prior to taking-off a multi-layer structure alternatively comprising first layers 1A, 1B, 1C, 1D, 1E in $Si_{1-x}Ge_x$ ($X \neq 0$) and second layers 2A, 2B, 2C, 2D, 2E in strained Si. We can thus carry out a number of takings-off according to the invention, from the same donor wafer 10, each taking-off being then followed by recycling of the remaining part of the donor wafer 10 in order to prepare it for a new taking-off. In this way, a first sSOI structure 30A and a second sSOI structure 30B will for example be formed from the same donor wafer 10. This type of taking-off is taught in the document US2004/0053477.

According to one particular embodiment of the invention, each strained layer (referenced "2" in figures 3a to 3e, "1" in figures 6a and 6b, and "2A", "2B", "2C", "2D" or "2E" in figures 7a and 7b) of the donor wafer is thick, which is to say that it has a relatively significant thickness without having the relaxation of its elastic strains. This has been made possible thanks to the formation by low temperature epitaxy. For example, a layer of strained Si deposited at temperatures of between approximately 450°C and 650°C on a growth support of $Si_{0.8}Ge_{0.2}$ can typically reach a thickness of between approximately 30 nm and 60 nm.

If such a thick strained layer is formed in this way, then care must be taken not to exceed a certain limit temperature (which is situated around the deposit temperature) in the following treatments, and in particular the treatments occurring between the deposit of the layer and the detachment of the latter, carried out by Smart-Cut®, in order to avoid relaxing of the strains.

Thus, in this case of thick strained layers, plasma activation prior to bonding (as discussed earlier) will be advantageously used and typically carried out at an ambient temperature lower than approximately 100°C. Furthermore, at least one layer of dielectric material bonding, such as $SiO_2$,

is advantageously formed on one or both of the two surfaces to be bonded, this layer made of dielectric material subsequently helping (i.e. after separation) to conserve the elastic strains. In complement to the plasma activation, a post-separation heat treatment at a temperature $T_2$ is advantageously lower than the deposit temperature of the thick strained layer in the case of no bonding layer being planned.

Of course, those skilled in the art can easily transpose the invention presented above to other materials than $Si_{1-x}Ge_x$ or strained Si, given that he knows the properties and physical grandeurs associated to these materials.

For example, by retracing the steps previously described, in reference to figures 3a to 3e, those skilled in the art could create a final structure 30 made of AsGa on insulator, if he chooses a donor wafer 10 whose first layer 1 is made of Ge and the second layer 2 made of AsGa, if he implants (as described above) in the Ge of the first layer 1, if he then transfers the remainder 1' of the Ge and the second layer 2 of AsGa to a host wafer 20 by means of an electrically insulating surface, and if he selectively removes the remainder 1" of Ge by using known selective etching techniques.

Similarly, a structure GaN-on-insulator can be for example manufactured from a donor wafer 10 comprising a first layer 1 made of SiC or Si (111) and a second layer 2 made of GaN. One or several stop layers made of AlGaN and/or AlN may possibly be provided in the GaN layer. After removal of the second layer 2 made of GaN, a selective etching comprising the removal of the GaN located above the stop layer can be used.

Thus, for example, dry etching using a plasma gas comprising $CH_2$, $H_2$ and possibly Ar, can etch the GaN quicker than AlN.

We can then possibly remove the stop layer to obtain finally a layer of GaN with little surface roughness and very homogeneous thickness.

We can also in the same way adapt the method according to the invention to other taken off layers in III-V or II-VI alloys.

We can also extend all of these materials to those including carbon in small quantities (around 5%) or doping agents.

## CLAIMS

1. Method of forming a structure comprising a layer that is taken off from a donor wafer, the donor wafer comprising prior to taking-off a first layer of a first material chosen among semiconductor materials and a second layer on the first layer of a second material chosen among semiconductor materials, the method comprising the following successive steps:

(a) implanting atomic species to form a weakness zone (4) under the second layer;

(b) bonding the donor wafer to a host wafer;

(c) supplying energy so as to disunite the taken-off layers of the donor wafer at the weakness zone;

(d) selective etching of the remaining part of the first layer with respect to the second layer;

wherein the implantation parameters are adjusted in step (a) so as to minimise the surface roughness which appears immediately after carrying out step (c), and wherein the method comprises moreover a step capable of strengthening the bonding, carried out at a temperature less than about 800°C (1,472°F).

2. Method according to the previous claim, wherein the step capable of strengthening the bonding is carried out prior to step (b) and comprises plasma activation.

3. Method according to any one of the preceding claims, wherein the step capable of strengthening the bonding is carried out after step (b) and comprises a thermal treatment.

4. Method according to the previous claim, wherein the thermal treatment is carried out at a temperature comprised between substantially 350°C and substantially 800°C, for a duration that can last up from 30 minutes to around four hours.

5. Method according to the previous claim, wherein the thermal treatment is carried out at a temperature comprised between substantially

550°C and substantially 800°C, for a duration that can last up from 30 minutes to around four hours.

6. Method according to any one of the three preceding claims, wherein the thermal treatment is carried out after step (c) and in continuity from step (c) in a same furnace.

7. Method according to the preceding claim, wherein the thermal treatment comprises a single temperature change as from the disuniting temperature of step (c) to the temperature chosen for the thermal treatment.

8. Method according to the preceding claim, wherein step (c) is carried out at around 500°C for a duration that can last up from 30 minutes to around 2 hours.

9. Method according to any one of the preceding claims, wherein the step capable of strengthening the bonding is carried so that prior to step (d), an energy greater than or equal to around 0.8 J/m² is obtained.

10. Method according to any one of the preceding claims, wherein said roughness which appears immediately after step (c) is less than approximately 40ÅRMS measured on a surface area of 10 × 10µm².

11. Method according to any one of the preceding claims, wherein the atomic species implanted during step (a) comprise two distinct atomic elements, step (a) thus being a co-implantation.

12. Method according to the preceding claim, wherein the co-implantation of step (a) is a co-implantation of helium and hydrogen.

13. Method according to the preceding claim, wherein the donor wafer comprises a SiGe layer, and wherein the co-implantation of step(a) is carried out according to implantation parameters adapted to form the embrittlement zone in said SiGe layer, and for the helium concentration peak to be located, in the thickness of the donor wafer, more in-depth than the hydrogen spreading zone and more in-depth than the embrittlement zone.

14. Method according to the preceding claim, in combination with any one of claims 3 to 7, wherein the thermal treatment is carried out at a temperature comprised between 575°C and 625°C.

15. Method according to one of the two preceding claims, wherein the dose of helium and hydrogen are chosen as being respectively of around $0.9.10^{16}/cm^2$ and of around $1.0.10^{16}/cm^2$.

16. Method according to any one of the preceding claims, wherein, after step (c), the method does not comprise mechanical polishing means.

17. Method according to any one of the preceding claims, wherein it further comprises, after step (d), a crystalline growth of the second material on the second layer to make the latter thicker.

18. Method according to any one of the preceding claims, wherein the first layer (1) is made of $Si_{1-x}Ge_x$ with $0<x\leq1$ and the second layer (2) is made of elastically strained Si.

19. Method according to any one of claims 1 to 17, wherein the donor wafer (10) comprises a support substrate made of bulk Si, a buffer structure made of SiGe, a first layer (1) of $Si_{1-x}Ge_x$ with $0<x\leq1$ and a second layer (2) made of elastically strained Si.

20. Method according to any one of claims 1 to 17, wherein the first layer (1) is made of elastically strained SiGe and the second layer (2) is made of $Si_{1-x}Ge_x$ with $0<x\leq1$, and the donor wafer (10) moreover comprises a third layer (3) made of $Si_{1-x}Ge_x$ under the first layer (1).

21. Method according to the preceding claim, wherein the implantation of step (a) is also carried out under the first layer and the method further comprises between step (c) and step (d), a selective etching of the remaining part of the third layer (3) with respect to the first layer (1).

22. Method according to any one of claims 1 to 17, wherein the donor wafer (10) comprises a support substrate made of bulk Si, a buffer structure made of SiGe, and a multi-layer structure alternatively comprising first layers (1A, 1B, 1C, 1D, 1E) made of $Si_{1-x}Ge_x$ ($x \neq 0$) and second layers (2A, 2B, 2C, 2D, 2E) made of strained Si, so as to be able to take off several times from a same donor wafer.

23. Method according to any one of claims 18 to 22, further comprising, prior to step (a), the formation of the strained layer at a deposit temperature of between around 450°C (842°F) and around 650°C (1,202°F), and wherein

the treatments used between this deposit and the detachment obtained at step (c) are carried out at temperatures less than or equal to the deposit temperature.

24. Method according to any one of the preceding claims, further comprising, prior to step (b), a step of forming a bonding layer on the donor wafer and/or on the host wafer, the bonding layer comprising an electrically insulating material, for example such as $SiO_2$, $Si_3N_4$ or $Si_xO_yN_z$.

25. Application of the method according to the preceding claim to the formation of a semiconductor-on-insulator structure.

26. Semiconductor-on-insulator structure obtained after carrying out all of the steps (a), (b) and (c) of the method according to claim 1, and after removing the contact between the taken-off layers (1', 2) and the remaining part of the donor wafer (10'), this structure having a surface roughness of less than about 40ÅRMS measured on a surface of 10 × 10µm², and a bonding energy greater than or equal to around 0.8 J/m².