RELAXATION OF LAYERS

The invention relates to the formation of a layer of unstrained crystalline material intended for electronics, optics or optronics applications, and more particularly the invention relates to the production of a structure comprising said layer.

A layer is termed "strained" herein when its crystalline structure is strained elastically under tension or in compression, with the result that its lattice parameter is substantially different from the nominal lattice parameter of its constituent material, the nominal lattice parameter of a material being its lattice parameter when in its bulk form and in its monocrystalline condition.

In contrast, a layer is termed "completely relaxed" or "unstrained" if the lattice parameter of its constituent crystalline material is substantially identical to its nominal lattice parameter.

Thus, an unstrained layer has a stable crystallographic structure when it is subjected to external stresses such as thermal stresses.

It is possible to find such unstrained layers directly in bulk wafers. However, the fabrication of bulk material is limited to a small number of materials such as silicon, AsGa, germanium, sapphire or others.

To produce unstrained layers constituted by other types of materials, it is known to form such a layer in the same wafer on a bulk substrate constituted by another crystalline material by interposing a buffer layer between the substrate and the layer.

In such a configuration, a "buffer layer" is understood to be a transition layer which adapts the lattice parameter of the layer formed with that of the substrate. Such a buffer layer may thus have a composition which varies gradually with depth, the gradual variation in the components of the buffer layer

then being directly associated with a gradual variation in its lattice parameter between the respective lattice parameters of the substrate and of the layer formed.

An example which can be mentioned is the formation of a layer of SiGe from a bulk silicon substrate via a SiGe buffer layer having a germanium composition that increases progressively between the substrate and the SiGe layer.

The "buffer layer" can thus be used to produce unstrained layers constituted by materials which do not exist or rarely exist in the bulk form.

Further, it may be advantageous to integrate said unstrained layers into semiconductor-on-insulator structures, a semiconductor-on-insulator structure then comprising the unstrained layer on an electrically insulating layer, said insulating material being comprised of a bulk substrate (such as a glass substrate, for example) or constituting a thick layer (such as a layer of SiO_2 or Si_3N_4) interposed between the unstrained layer and a subjacent bulk substrate. Such semiconductor-on-insulator structures have better electrical and/or optical properties compared with bulk structures, thereby improving the performance of components produced in the unstrained layer.

A semiconductor-on-insulator layer is typically produced by layer transfer from a donor wafer to a receiver wafer, the donor wafer possibly being bulk or composite, such as a wafer comprising a buffer layer and a sub-epitaxial unstrained layer.

Said layer transfer techniques comprise a wafer bonding step, the donor wafer being bonded with the receiver wafer, then a step of lifting off part of the donor wafer to leave only said transferred layer on the receiver wafer.

The donor wafer may, for example, be reduced by chemical-mechanical attack of the back portion (for

example by polishing, grinding, chemical-mechanical planarization, chemical etching, selective chemical etching, etc) using techniques known as "polish-back" and/or "etch-back", or by cutting the donor wafer after atomic implantation at the zone which is to be cut, using a technique termed Smart Cut® which is known to the skilled person (by way of example, reference may be made to the work entitled "Silicon-on-Insulator Technology: Materials to VLSI, 2nd Edition" by Jean-Pierre Colinge, Kluwer Academic Publishers, pp 50 and 51).

A technique for transferring a layer of unstrained SiGe from a composite donor wafer comprising a buffer layer using an etch-back technique is described in International patent application WO-A-01/99169.

However, said unstrained layer transfer technique is lengthy, expensive, and results in the loss of the donor wafer following transfer.

WO-A-02/27783 describes a Smart Cut® technique for transferring an unstrained SiGe layer. That technique allows the lifted portion of the donor wafer to be recovered for possible recycling.

However, said layer transfer cannot ensure perfect homogeneity of its thickness, and an additional polishing step has to be carried out to increase the short range homogeneity. However, said polishing reduces the long range homogeneity (i.e. homogeneity measured between the centre and edges of the wafer).

WO-A-02/15244 and WO-A-04/06327 describe a method of transferring a layer of unstrained SiGe from a donor wafer including a layer of strained Si between the buffer layer and the unstrained SiGe layer. The method consists in transferring the unstrained SiGe layer and the strained Si layer onto a receiver wafer, then selectively removing the strained Si as opposed to the unstrained SiGe layer. That produces a final layer of unstrained SiGe having short and long range homogeneity using the

Smart Cut® technique and without having to carry out final polishing.

However, during transfer of the strained Si layer, heat treatments are applied, and may cause diffusion of germanium into the strained Si layer, thus reducing the selectivity between the strained Si and the unstrained SiGe which is necessary for final chemical etching. Given that a strained Si layer is thin, this loss of selectivity may lead to the unstrained SiGe layer being attacked, and thus to a reduction in its quality and in its short range thickness homogeneity.

A principal aim of the invention is to overcome all of these disadvantages by proposing a method of forming a completely relaxed layer having good thickness homogeneity.

A further aim of the invention is to produce a semiconductor-on-insulator layer having a layer of unstrained crystalline material and having good thickness homogeneity.

The invention achieves these aims by proposing a method of forming a layer of elastically unstrained crystalline material intended for electronics, optics, or optronics applications, characterized in that the method is implemented from a structure comprising a first crystalline layer which is elastically strained under tension (or respectively in compression) and a second crystalline layer which is elastically strained in compression (or respectively under tension), the second layer being adjacent to the first layer, in that the method comprises a step of diffusion between the two layers so that the differences between the respective compositions of the two layers reduces progressively until they are identical, the two layers then forming just a single final layer of crystalline material having, in aggregate, a uniform composition, and in that the respective compositions, thicknesses, and degrees of

strain of the two layers are initially selected so that, after diffusion, the material then constituting the final layer no longer, in aggregate, exhibits elastic strain.

Other characteristics of this method of forming the unstrained layer are as follows:

· the lattice parameters of the first and second strained layers are respectively equal to the nominal lattice parameter of the material constituting the final layer;

· the second layer is a layer which is epitaxially grown on the first layer;

· the first and second layers have at least one element in their respective compositions in common;

· the first layer is formed from $Si_{1-x}Ge_x$, the second layer is formed from $Si_{1-y}Ge_y$ and the final layer is formed from $Si_{1-z}Ge_z$, $\underline{x}$ and $\underline{y}$ respectively being in the range 0 (comprised) to 1 (comprised), $\underline{x}$ being substantially different from $\underline{y}$, and:

$z = (x*th_1 + y*th_2)/(th_1 + th_2)$

th_1 being the thickness of the first layer;

th_2 being the thickness of the second layer;

and the respective lattice parameters of the first and second strained layers are respectively equal to the nominal lattice parameter of $Si_{1-z}Ge_z$;

· said structure further comprises a layer of amorphous material located beneath the two crystalline layers;

· the layer of amorphous material is electrically insulating;

· the layer of amorphous material comprises at least one of the following materials: SiO_2, Si_3N_4, $Si_xO_yN_z$;

· diffusion is carried out by heat treatment.

In a second aspect, the invention provides a method of producing a structure comprising an elastically unstrained crystalline layer intended for electronics,

optics, or optronics applications, characterized in that it comprises the following steps:

· crystal growing a second crystalline layer on a first crystalline layer which is elastically strained under tension (or respectively in compression), so that the second layer is elastically strained in compression (or respectively under tension) by the first layer, and so that the thickness of the second layer is selected to be of the order of a reference thickness, the reference thickness corresponding to a thickness for which the assembly of elements composing the second layer and the assembly of elements composing the first layer, once combined together, can form a uniform layer which, in aggregate, is unstrained;

· diffusing elements between the two layers so that the differences between the respective compositions of the two layers is progressively reduced until they are identical, the two layers then forming just a single final layer of a crystalline material having a composition which, in aggregate, is uniform and elastically unstrained, producing at least part of said structure.

Further characteristics of this method of producing a structure comprising an unstrained layer are as follows:

· the lattice parameter of the first layer is selected so as to be substantially equal to the nominal parameter of the material composing the final layer;

· crystalline growth is also carried out so that the thickness of the second layer is less than or equal to a critical thickness beyond which elastic strains would substantially relax;

· further, before the crystalline growth step, the first layer is bonded with a receiver substrate, said structure which is finally formed thus comprising said final layer and also said receiver substrate;

· bonding is carried out via a bonding layer formed on one and/or the other of the faces to be bonded;

· the bonding layer comprises at least one of the following two materials: SiO_2, Si_3N_4;

· bonding is molecular and is then reinforced by a suitable heat treatment;

· the first layer is comprised in a wafer at the time of bonding, and the method further comprises, between the bonding and crystalline growth steps, lifting off the portion of the wafer which does not comprise the first layer;

· the portion of the wafer which does not comprise the first layer is lifted off by means of at least one of the following techniques: grinding, chemical mechanical planarization (CMP), selective CMP, chemical etching, selective chemical etching;

· prior to bonding, the method further comprises implanting atomic species into the wafer to create therein a zone of weakness at a depth which is substantially equal to the thickness of the first layer; and the wafer portion is lifted off by subjecting the zone of weakness to stresses which are capable of rupturing the weak bonds and thereby detaching said first layer from the remainder of the wafer;

· further, between lifting off part of the wafer and crystalline growth, a step of finishing the surface of the first layer is carried out to prepare its surface for crystalline growth of the second layer;

· the first layer is formed from $Si_{1-x}Ge_x$, the second layer is formed from $Si_{1-y}Ge_y$ and the final layer is formed from $Si_{1-z}Ge_z$, $\underline{x}$ and $\underline{y}$ respectively being in the range 0 (comprised) to 1 (comprised), $\underline{x}$ being substantially different from $\underline{y}$, and:

$z = (x*th_1 + y*th_2)/(th_1 + th_2)$

th_1 being the thickness of the first layer;

th_2 being the thickness of the second layer;

and the lattice parameter of the first strained layer is substantially equal to the nominal lattice parameter of $Si_{1-z}Ge_z$;

· the first layer is formed from strained Si and is comprised in a strained silicon-on-insulator substrate (sSOI).

Other characteristics, aims, and advantages are described in the following non -limiting description of the invention, illustrated by the following figures:

Figures 1A and 1C represent different steps in a method in accordance with the invention for producing a structure comprising an unstrained layer.

Figures 2A and 2B respectively represent a semiconductor-on-insulator structure before and after diffusion in accordance with the invention.

Figures 3A to 3E represent different steps in a method in accordance with the invention for producing a particular structure comprising an unstrained layer.

The method of the invention comprises a step of diffusion between two elastically strained crystalline layers to form a single final crystalline layer with an elastically unstrained homogeneous composition.

In Figure 1A, said unstrained layer is formed from a structure 30 comprising a first crystalline layer elastically strained under tension 1 (tension being shown diagrammatically in the figure by diverging arrows) and a second crystalline layer elastically strained in compression 2 (compression being shown in the figure by converging arrows), the second layer 2 being adjacent to the first layer 1.

In an alternative configuration of the invention, the first layer 1 may, in contrast, be in compression and the second layer 2 is under tension, without in any way modifying the diffusion step which is then carried out.

The structure 30 may be formed only by two layers 1 and 2, or it may comprise a support (such as a stiffener

or a growth substrate) on one side of one and/or the other of the two layers 1 and 2.

In a first configuration, the layer 2 has the characteristics of a layer which has been epitaxially grown on the layer 1, this layer then being a growth substrate. Alternatively, the layer 1 may have the characteristics of an epitaxially grown layer on the layer 2, said layer then acting as a growth substrate.

Crystalline growth of the epitaxial layer may have been obtained using the known techniques of LPD, CVD and MBE (respectively low power deposition, chemical vapor deposition, and molecular beam epitaxy).

To avoid the appearance of plastic type defects in the epitaxially grown layer while guaranteeing the desired elastic strain, it is desirable for the thickness of the epitaxially grown layer to be below a critical thickness essentially determined as a function of differences in the nominal lattice parameters of the respective materials composing the two layers 1 and 2. This critical thickness can be determined from prior knowledge and publications. As an example, reference could be made to the document "High Mobility Si and Ge Structures" by Friedrich Schaffler ("Semiconductor Science Technology" 12 (1997) 1515-1549) to determine the critical thickness of a layer 1 of $Si_{1-x}Ge_x$ and for a layer 2 of $Si_{1-y}Ge_y$ ($\underline{x}$ being different from $\underline{y}$).

In a second configuration, the layers 1 and 2 have been bonded together using known bonding techniques (see, for example, "Semiconductor Wafer Bonding Science and Technology" by Q.-Y. Tong and U. Gösele - a Wiley Interscience publication, Johnson Wiley & Sons, Inc - for more details). Thus, for example, molecular bonding of hydrophilic surfaces or surfaces rendered hydrophilic may be selected, or bonding after plasma treatment of one and/or the other of two surfaces to be bonded, followed

by conventional annealing or RTA treatment (rapid thermal annealing).

In the case in which the two layers 1 and 2 have been bonded to each other, it is essential to select bonding techniques which are not susceptible to hindering diffusion between the two layers 1-2 which is then carried out in accordance with the invention. In particular, care is taken to prepare, in known manner, the surfaces to be bonded to smooth them and clean them effectively so that they have no more contaminants and isolated particles which may perturb diffusion. Chemical treatments which are adapted to cleaning surfaces to be bonded may be carried out, such as weak chemical etching, RCA treatment, ozone baths, rinsing, etc. Mechanical or chemical-mechanical treatments may also be carried out, such as polishing, abrasion, CMP (chemical mechanical planarization) or atomic species bombardment. Further, bonding will be carried out without a bonding layer (of the SiO_2 or Si_3N_4 type, for example) or with a bonding layer which is so thin that it cannot substantially prevent or slow diffusion between the two layers 1 and 2.

The respective compositions, thicknesses and degrees of strain of the two layers 1 and 2 are selected so that, after carrying out diffusion, the material then constituting the final unstrained layer to be formed is no longer, in aggregate, elastically strained.

In particular, the lattice parameter of strained layers 1 and 2 are advantageously respectively equal to the nominal lattice parameter of the material constituting the final layer that is to be formed.

In particular, the respective compositions and thicknesses of the strained layers 1 and 2 are advantageously selected so that, once homogenization by diffusion of the two layers 1 and 2 into a final layer has been achieved, the final layer has the desired composition.

Referring to Figure 1B, the method comprises a step of diffusion between the two layers 1 and 2 so that the differences between their respective compositions are progressively reduced.

This phenomenon thus entrains displacements between the layers 1 and 2 of the constituent elements of their materials, to progressively reduce their differences in compositions (the displacements between the layers 1 and 2 being shown in the figure by arrows).

Diffusion is advantageously carried out by heat treatment, adapted to one or more predetermined temperature(s) respectively during one or more time period(s) to obtain the desired result, i.e. a final elastically unstrained layer. As an example, heat treatment may be carried out at a temperature in the range 900°C to 1200°C for 30 minutes (min) to a few hours (h).

Figure 1C shows the result obtained after carrying out diffusion: the respective compositions of the two layers 1 and 2 are substantially identical to each other, the two layers 1 and 2 then forming just a single final layer 3 formed from a crystalline material having a composition which is uniform and elastically unstrained.

In a particular configuration of the invention, the materials constituting the layers 1 and 2 may initially have at least one element of their respective compositions in common. Thus, if the composition of one of the two layers 1 or 2 is such that it comprises more of this element than the other layer, more diffusion of that element will occur from that first layer towards the other layer to homogenize the composition of the assembly.

As an example, consider that the first layer 1 is formed from $Si_{1-x}Ge_x$, the second layer is formed from $Si_{1-y}Ge_y$. According to the invention, their thicknesses and degrees of strain (i.e. their respective lattice

parameters depending on their compositions) will be selected to obtain a final layer 3 of unstrained $Si_{1-z}Ge_z$ ($\underline{x}$ and $\underline{y}$ respectively being in the range 0 (comprised) and 1 (comprised), $\underline{x}$ being substantially different from $\underline{y}$):

then, $\underline{x}$, $\underline{y}$, th_1 and th_2 will be selected so that:

$$z = (x*th_1 + y* th_2)/(th_1 + th_2) \quad (1)$$

- th_1 being the thickness of the first layer 1;
- th_2 being the thickness of the second layer 2.

Thus, the respective lattice parameters of the first and second layers strained 1 and 2 are respectively equal to the nominal lattice parameter of $Si_{1-z}Ge_z$.

Clearly, care will be taken that th_1 and th_2 are respectively smaller than the critical thicknesses of layers 1 and 2.

Figure 2A shows a particular implementation of the invention in the case in which the structure 30 is initially a sSOI (strained silicon-on-insulator) structure, thus comprising a first layer 1 of strained Si and a bulk insulating substrate in a first configuration (not shown), or a first layer 1 of strained Si, a bulk substrate 20 and an interposed insulating layer 4 in a second configuration (shown).

This type of sSOI substrate 30 is commercially available.

In this example, the degree of strain of the first layer 1 of Si is fixed by selecting a sSOI substrate 30 with a predetermined degree of strain. The lattice parameter of the final layer 3 to be formed is thereby selected.

In a second step, the composition of the second layer 2 to be epitaxially grown and the respective thicknesses of the first layer 1 (which may then optionally be modified) and the second layer 2 are selected to form a final layer 3 having, after

homogenizing the two layers 1-2 by diffusion, a nominal lattice parameter equal to that of the first layer 1.

As an example, if the composition of the second layer 2 is selected to be $Si_{1-y}Ge_y$, simple epitaxial growth of the second layer of $Si_{1-y}Ge_y$ on the sSOI substrate 30 by selecting, in accordance with the invention, its thickness by reference to the thickness of the first layer 1 (see relationship (1) above), followed by a simple step of diffusion by heat treatment in accordance with the invention, a final layer 3 of unstrained $Si_{1-z}Ge_z$ could be obtained.

The initial choice of the composition of $Si_{1-y}Ge_y$ may also be guided by limitations as regards the critical thickness. In fact, if a concentration y of Ge of more than a predetermined limiting concentration is selected, the thickness th_2 to be selected to finally form a layer 3 of unstrained $Si_{1-z}Ge_z$ is greater than the critical thickness. A second layer 2 is thereby obtained with plastic strain relaxations (dislocations, stacking faults and/or other plastic defects); thus, the final layer 3 is of poor crystalline quality.

Certain conditions for epitaxial growth, such as those described in "Strain Relaxation Kinetics in $Si_{1-z}Ge_z$/Si heterostructures" by D.C. Houghton (J. Appl. Phys. 70 (4), 15 August 1991) can, however, produce crystalline growth of the layer beyond the theoretical critical thickness; reference should be made to "Defects in Epitaxial Multilayers", J.W. Matthews et al (Journal of Crystal Growth 27 (1974) 118-125), which describes the physical phenomena appearing beyond the critical thickness, and the influence of deposition techniques on the appearance of such phenomena.

From the structure 30 thus formed, diffusion in accordance with the invention is then carried out. As an example, it is possible to select a temperature of about 1050°C for about 2 hours.

Figures 3A to 3E we show several steps in a further particular method in accordance with the invention, comprising the following steps:

(1) epitaxial growth of a first thin layer 1 of elastically strained crystalline material on a donor surface 10;

(2) bonding a receiver substrate 20 with the donor substrate 10 at the strained layer 1;

(3) lifting off the donor surface 10;

(4) crystalline growth of a second elastically strained layer 2;

(5) diffusion in accordance with the invention.

Figure 3A shows a wafer constituted by a donor substrate 10 and a first strained layer 1 of $Si_{1-x}Ge_x$ ($\underline{x}$ being in the range 0 (comprised) to 1 (comprised)).

In one configuration of the donor substrate 10, it is a pseudo-substrate comprising a buffer layer (as defined above) on a support substrate (not shown in Figure 3A). The buffer layer of SiGe may thus, for example, be formed by epitaxy from a support substrate of bulk monocrystalline Si and, in aggregate, has an increase in its Ge concentration through its thickness, so as to gradually modify the nominal lattice parameter of the Si of the support substrate and that of a SiGe. The buffer layer is arranged so as to further comprise an upper layer of relaxed $Si_{1-w}Ge_w$ ($\underline{w}$ differing from $\underline{x}$) having a predetermined lattice parameter and having a thickness which is sufficiently great to be able to impose its lattice parameter on the subjacent strained first layer 1 without that layer 1 substantially influencing the upper layer's crystalline structure.

Regardless of the configuration selected for the donor substrate 10, said substrate 10 has a crystalline structure which induces elastic stresses and a low density of plastic defects in the strained layer 1.

Since Ge has a lattice parameter which is more than 4.2% greater than Si, the material selected to constitute said strained layer 1 is thus strained under tension if x is smaller than w, and is in compression if x is less than w.

The first strained layer 1 is advantageously formed on the donor substrate 10 by crystalline growth, such as epitaxy using the known techniques of LPD, CVD and MBE.

It is preferable to deposit the layer 1 so that it has a substantially constant thickness, so that it has substantially constant intrinsic properties and/or to facilitate future bonding with the receiver substrate 20 (as shown in Figure 3B).

To prevent relaxation of the strained layer 1 or the appearance of internal plastic type defects, it is preferable to keep the thickness of this layer 1 below a critical thickness for elastic strain.

Regarding critical thickness values for layers of $Si_{1-x}Ge_x$, reference should be made in particular to the document entitled "High Mobility Si and Ge Structures" by Friedrich Schäffler ("Semiconductor Science Technology" 12 (1997) 1515-1549).

For other materials, the skilled person will refer to the prior art for the critical thickness for elastic strain of the material selected for the strained layer 1 formed on the donor substrate 10.

Thus, a layer of $Si_{1-x}Ge_x$ (x in the range 0.10 to 0.30) epitaxially grown on relaxed Si has a typical thickness in the range about 200 Å [angstroms] to 2000 Å, preferably in the range 200 Å to 500 Å, in particular by adapting the growth parameters.

Once formed, the strained layer 1 thus has a lattice parameter which is substantially close to that of its growth substrate 10 and has a lattice parameter which is substantially equal to the lattice parameter of the

unstrained layer which is to be formed in accordance with the invention.

Figure 3B shows bonding of the donor substrate 10 with the receiver substrate 20.

Before bonding, an optional step of forming a bonding layer on at least one of the two surfaces to be bonded may be carried out, said bonding layer having binding properties at ambient temperature or at higher temperatures.

Thus, for example, forming a layer of SiO_2 or Si_3N_4 may improve the bonding quality, in particular if the other surface to be bonded is formed from SiO_2 or contains Si.

A SiO_2 bonding layer is then advantageously produced by depositing atomic species of SiO_2 or by thermal oxidation of the surface to be bonded if the surface thereof contains Si.

A step of preparing the surfaces to be bonded is advantageously carried out prior to bonding to render the surfaces as smooth as possible and as clean as possible.

The bonding operation per se is carried out by bringing the surfaces to be bonded into contact. The bonds are preferably molecular in nature, exploiting the hydrophilic properties of the surfaces to be bonded. The bonding surfaces may also be plasma treated.

The bonded assembly may be annealed to reinforce the bonds, for example by modifying the nature of the bonds, such as covalent bonds or other bonds.

Thus, annealing may accentuate the bonds, in particular if a bonding layer has been formed prior to bonding.

More details regarding bonding techniques may be obtained from the document entitled "Semiconductor Wafer Bonding" (Science and Technology, Interscience Technology) by Q.Y. Tong, U. Gösele, Wiley.

Referring to Figure 3C, once the assembly is bonded, the donor substrate 10 is removed.

The strain in the first layer 1 is thus essentially conserved due to binding forces (see, in particular, WO-A-04/006326, hereby incorporated by reference, for further details).

In one implementation, the material is removed by detaching at least part of the donor substrate 10 at a zone of weakness present in the donor substrate 10, by supplying energy.

This zone of weakness (not shown) is a zone substantially parallel to the bonding surface, having weakened bonds therein, said weak bonds being capable of being ruptured when a suitable amount of energy is supplied, such as thermal and/or mechanical energy.

The zone of weakness may have been formed by implanting atomic species into the donor substrate 10.

The implanted species may be hydrogen, helium, a mixture of the two species or other, preferably light, species.

Said implantation may be carried out before bonding, before or after forming the strained layer 1.

The bonds in the zone of weakness are principally weakened by the choice of the dose of implanted species. In the case of hydrogen implantation, the dose is typically in the range 10^{16} cm^{-2} to 10^{17} cm^{-2}, and more precisely in the range from about 2×10^{16} cm^{-2} to about 7×10^{16} cm^{-2}.

Detachment at said zone of weakness is then normally carried out by supplying mechanical and/or thermal energy.

For more details regarding this Smart Cut® method, reference should be made to the document entitled "Silicon-on-Insulator Technology: Materials to VLSI, 2nd Edition" J.-P. Collinge, published by "Kluwer Academic Publishers", pp 50 and 51.

After detachment at the zone of weakness, the optional remaining portion of the donor substrate 10 is removed so as to retain only the strained layer 1 on the receiver substrate 20.

Finishing techniques such as polishing, abrasion, CMP, RTA, sacrificial oxidation, chemical etching, used alone or in combination, may then be carried out (reinforcement of bonding interface, elimination of roughness, curing defects, etc).

Advantageously, finishing material removal employs, at least at the end, a selective chemical etch, in combination or otherwise with mechanical means.

Alternatively, a further technique for removing material without detachment and without a zone of weakness may be carried out for the step of lifting off the donor substrate 10.

It consists of carrying out chemical etching and/or chemical-mechanical etching.

As an example, it is possible to selectively etch the material or materials of the donor substrate 10 to be lifted off, using an "etch-back" type method.

That technique consists of etching the donor substrate 10 "from the back", i.e. from the free face of the donor substrate 10.

Wet etches employing etching solutions adapted to the materials to be removed may be carried out.

Dry etching may also be employed to remove material, such as plasma etches or by sputtering.

The etch or etches may be preceded or followed by mechanical attack of the donor substrate 10, such as grinding, polishing, mechanical etching or atomic species sputtering.

The etch or etches may be accompanied by mechanical attack, such as polishing, optionally combined with the action of mechanical abrasives in a CMP method.

All of said techniques for removing material from the donor substrate 10 are proposed by way of example in the present document, but do not in any way constitute a limitation, the invention extending to all types of techniques that can remove the donor substrate 10, in accordance with the method of the invention.

Referring to Figure 3D, epitaxy in accordance with the invention of a second strained layer 2 of $Si_{1-y}Ge_y$ is carried out, as described above.

If the first layer 1 is strained under tension (i.e. if $\underline{x}$ is smaller than $\underline{w}$), the second layer 2 is selected so that it is in compression (i.e. $\underline{y}$ is greater than $\underline{w}$).

Consequently, if the first layer 1 is in compression (i.e. if $\underline{x}$ is greater than $\underline{w}$), the second layer 2 is selected so that it is under tension (i.e. $\underline{y}$ is smaller than $\underline{w}$).

The choice of compositions, thicknesses and lattice parameters is determined in accordance with that explained above.

Alternatively, the second layer 2 may be epitaxially grown on the first layer 1 before bonding, bonding then being carried out at the surface of the layer 2. This produces a structure 30 having, in succession, the receiver substrate 20, the layer 2 then the layer 1 (in contrast to Figure 3D).

Referring to Figure 3E, a diffusion heat treatment in accordance with the invention is carried out, to form a structure 30 having a final layer 3 of $Si_{1-z}Ge_z$. Said structure is a SiGeOI structure in the case in which the receiver substrate 20 is an electrical insulator or a sufficiently thick bonding layer is comprised between the layer 3 of $Si_{1-z}Ge_z$ and the receiver substrate 20.

Once the final structure 30 is obtained, finishing treatments may be carried out, for example an anneal.

Electronic, optic and optronic components may then be produced in the final layer 3.

One or more epitaxial growth steps of any kind may also be carried out on the final structure 30 (refer to Figure 1C, 2B or 3E), such as epitaxial growth of a layer of SiGe or SiGeC, or epitaxy of a layer of strained SiC or Si, or successive epitaxies of alternating SiGe or SiGeC layers and layers of strained SiC or Si to form a multilayered structure.

The present invention is not limited to strained layers 1 and 2 of Si or SiGe, but also extends to other types of materials, such as III-V or II-VI type alloys, or to other crystalline materials.

In the crystalline layers discussed here, other constituents may be added, such as doping elements or carbon with a concentration of carbon in the layer under consideration which is 50% or substantially lower or, more particularly, with a concentration of 5% or less.

CLAIMS

1. A method of forming a layer of elastically unstrained crystalline material intended for electronics, optics, or optronics applications, characterized in that the method is implemented from a structure comprising a first crystalline layer which is elastically strained under tension (or respectively in compression) and a second crystalline layer which is elastically strained in compression (or respectively under tension), the second layer being adjacent to the first layer, in that the method comprises a step of diffusion between the two layers so that the differences between the respective compositions of the two layers reduces progressively until they are substantially the same, the two layers then forming just a single final layer of crystalline material having, in aggregate, a uniform composition, and in that the respective compositions, thicknesses, and degrees of strain of the two layers are initially selected so that, after diffusion, the material then constituting the final layer no longer, in aggregate, exhibits elastic strain.

2. A method of forming a layer of elastically unstrained crystalline material according to the preceding claim in which the lattice parameters of the first and second strained layers are respectively equal to the nominal lattice parameter of the material constituting the final layer.

3. A method of forming a layer of elastically unstrained crystalline material according to any preceding claim, in which the second layer is a layer which is epitaxially grown on the first layer.

4. A method of forming a layer of elastically unstrained crystalline material according to any preceding claim, in

which the first and second layers have at least one element in their respective compositions in common.

5. A method of forming a layer of elastically unstrained crystalline material according to the preceding claim, in which the first layer is formed from $Si_{1-x}Ge_x$, the second layer is formed from $Si_{1-y}Ge_y$ and the final layer is formed from $Si_{1-z}Ge_z$, $\underline{x}$ and $\underline{y}$ respectively being in the range 0 (comprised) to 1 (comprised), $\underline{x}$ being substantially different from $\underline{y}$, and:

$z = (x*th_1 + y*th_2)/(th_1 + th_2)$

th_1 being the thickness of the first layer;

th_2 being the thickness of the second layer;

and the respective lattice parameters of the first and second strained layers are respectively equal to the nominal lattice parameter of $Si_{1-z}Ge_z$.

6. A method of forming a layer of elastically unstrained crystalline material according to any preceding claim, in which said structure further comprises a layer of amorphous material located beneath the two crystalline layers.

7. A method of forming a layer of elastically unstrained crystalline material according to the preceding claim, in which the layer of amorphous material is electrically insulating.

8. A method of forming a layer of elastically unstrained crystalline material according to the preceding claim, in which the layer of amorphous material comprises at least one of the following materials: SiO_2, Si_3N_4, $Si_xO_yN_z$.

9. A method of forming a layer of elastically unstrained crystalline material according to any preceding claim, in which the diffusion is carried out by heat treatment.

10. A method of producing a structure comprising an elastically unstrained crystalline layer intended for electronics, optics, or optronics applications, characterized in that it comprises the following steps:

crystal growing a second crystalline layer on a first crystalline layer which is elastically strained under tension (or respectively in compression), so that the second layer is elastically strained in compression (or respectively under tension) by the first layer, and so that the thickness of the second layer is selected to be of the order of a reference thickness, the reference thickness corresponding to a thickness for which the assembly of elements composing the second layer and the assembly of elements composing the first layer, once combined together, can form a uniform layer which, in aggregate, is unstrained;

diffusing elements between the two layers so that the differences between the respective compositions of the two layers is progressively reduced until they are substantially the same, the two layers then forming just a single final layer of a crystalline material having a composition which, in aggregate, is uniform and elastically unstrained, producing at least part of said structure.

11. A method of producing a structure according to the preceding claim, in which the lattice parameter of the first layer is selected so as to be substantially equal to the nominal lattice parameter of the material composing the final layer.

12. A method of producing a structure according to either one of the two preceding claims, in which crystalline

growth is also carried out so that the thickness of the second layer is less than or equal to a critical thickness beyond which elastic strains would substantially relax.

13. A method of producing a structure according to any one of the three preceding claims, further comprising, before the crystalline growth step, bonding the first layer with a receiver substrate, said structure which is finally formed thus comprising said final layer and also said receiver substrate.

14. A method of producing a structure according to the preceding claim, in which bonding is carried out via a bonding layer formed on one and/or the other of the faces to be bonded.

15. A method of producing a structure according to the preceding claim, in which the bonding layer comprises at least one of the following two materials: SiO_2, Si_3N_4.

16. A method of producing a structure according to any one of the two preceding claims, in which bonding is molecular and is then reinforced by a suitable heat treatment.

17. A method of producing a structure according to any one of the three preceding claims, in which the first layer is comprised in a wafer at the time of bonding, and the method further comprises, between the bonding and crystalline growth steps, lifting off the portion of the wafer which does not comprise the first layer.

18. A method of producing a structure according to the preceding claim, in which the portion of the wafer which does not comprise the first layer is lifted off by means

of at least one of the following techniques: grinding, CMP, selective CMP, chemical etching, selective chemical etching.

19. A method of producing a structure according to claim 17, further comprising, prior to bonding, implanting atomic species into the wafer to create therein a zone of weakness at a depth which is substantially equal to the thickness of the first layer; and in which a portion is lifted off by subjecting the zone of weakness to stresses which are capable of rupturing the weak bonds and thereby detaching said first layer from the remainder of the wafer.

20. A method of producing a structure according to any one of claims 17 to 19, further comprising, between lifting off part of the wafer and crystalline growth, a step of finishing the surface of the first layer to prepare its surface for crystalline growth of the second layer.

21. A method of producing a structure according to any one of claims 10 to 20, in which the first layer is formed from $Si_{1-x}Ge_x$, the second layer is formed from $Si_{1-y}Ge_y$ and the final layer is formed from $Si_{1-z}Ge_z$, $\underline{x}$ and $\underline{y}$ respectively being in the range 0 (comprised) to 1 (comprised), $\underline{x}$ being substantially different from $\underline{y}$, and:

$z = (x*th_1 + y*th_2)/(th_1 + th_2)$

th_1 being the thickness of the first layer;

th_2 being the thickness of the second layer;

and in which the lattice parameter of the first strained layer is substantially equal to the nominal lattice parameter of $Si_{1-z}Ge_z$.

22. A method of producing a structure according to any one of claims 10 to 21, in which the first layer is

formed from strained Si and is comprised in a strained silicon-on-insulator substrate (sSOI).