FORMATION OF A RELAXED USEFUL LAYER FROM A WAFER WITH NO BUFFER LAYER

The present invention relates to the formation of a useful layer from a wafer, the wafer comprising a substrate and a strained layer chosen respectively from crystalline materials for an application in microelectronics, in optics or in optoelectronics.

In this text, a layer is said to be "relaxed" if the crystalline material of which it is composed has a lattice parameter substantially identical to its nominal lattice parameter, that is to say the lattice parameter of the material in its bulk form in equilibrium.

Conversely, a "strained" layer refers to any layer of a crystalline material whose crystal structure is elastically strained in tension or in compression during crystal growth, such as epitaxial growth, requiring its lattice parameter to be substantially different from the nominal lattice parameter of this material.

It is sometimes useful or advantageous to form, in the same wafer, a layer of a first crystalline material on a substrate of a second crystalline material having different nominal lattice parameters respectively, while keeping its crystal structure, at least in part, relaxed and/or without an excessive number of crystallographic defects.

For this purpose, it is known to insert a buffer layer between the substrate and the formed layer.

In this configuration, a "buffer layer" is understood to mean a transition layer that matches the lattice parameter of the formed layer with that of the substrate.

For this purpose, such a buffer layer may have a composition that gradually varies through the

thickness, the gradual variation of 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 formed layer.

It may also have a more complex form, such as a variable-content compositional variation, an inversion in the sign of the content, or discontinuous step changes in composition.

The formation of such a variable composition takes a long time and is often complex to implement.

Moreover, to minimize its density of crystallographic defects, the thickness of a buffer layer is usually large, typically between one and several microns.

The production of such a buffer layer therefore involves often lengthy, difficult and expensive processing.

Another technique of relaxing elastic strains in a formed layer giving a similar result with substantially less processing required is given by B. Höllander et al., for example in the document entitled "*Strain relaxation of pseudomorphic $Si_{1-x}Ge_x$ / Si(100) heterostructures after hydrogen or helium ion implantation for virtual substrate fabrication*" (in Nuclear and Instruments and Methods in Physics Research B 175-177 (2001) 357-367).

The process described relates to the relaxation of a strained SiGe layer in compression, this layer being formed on an Si substrate.

The technique employed comprises the implantation of hydrogen or helium ions through the surface of the strained layer into the Si substrate to a defined

depth.

A crystalline perturbation created by the ion implantation and located in a thickness of the Si substrate lying between the implantation region and the SiGe layer causes, under a heat treatment, a certain relaxation of the SiGe layer.

This technique therefore makes it possible, by simple atom or molecule implantation into the substrate, to produce a relaxed or pseudo-relaxed formed layer in an intermediate buffer layer.

This technique therefore seems to be less lengthy, easier to implement and less expensive than that which includes the formation of a buffer layer.

It would be of interest to use this technique to subsequently integrate this relaxed or pseudo-relaxed layer into a structure for the fabrication of components, especially for electronics or optoelectronics.

The objective of the present invention is to succeed in carrying out this layer integration by providing, according to a first aspect, a process for forming a useful layer from a wafer, the wafer comprising a supporting substrate and a strained layer chosen respectively from crystalline materials for an application in microelectronics, in optics or in optoelectronics, characterized in that it comprises the following steps:

(a) formation in the supporting substrate of a region of perturbation at a defined depth capable of forming structural perturbations;

(b) supply of energy to cause at least relative relaxation of the elastic strains in the strained layer; and

(c) removal of a portion of the wafer on the

opposite side to the relaxed strained layer, the useful layer being the remaining portion of the wafer.

Further preferred aspects of the recycling process according to the invention are those given in Claims 2 to 34.

According to a second aspect, the subject of the invention is an application of a removal process in Claim 35.

According to a third aspect, the subject of the invention is source wafers, that donate a thin layer by taking-off, and a structure, which are given in Claims 36 to 39.

Further features, objects and advantages of the present invention will become more clearly apparent on reading the detailed description with reference to the following figures:

Figure 1 shows the various steps of a process according to the invention.

Figure 2 shows a wafer according to the invention from which a useful layer will be taken off.

Figure 3 shows another wafer according to the invention from which a useful layer will be taken off.

The present invention involves:

- a source wafer in which a useful layer comprising:
  - a supporting substrate; and
  - a strained layer on the supporting substrate;
- a receiving substrate that forms a support for the formation of the useful layer.

In this text, and in general, a "useful layer" will

refer to that portion of the source wafer being formed on the receiving substrate.

A principal objective of the present invention consists in forming a relaxed or pseudo-relaxed useful layer on the receiving substrate from the source wafer, the useful layer being included at least partly in the strained layer of the source wafer.

The strained layer had been relaxed or pseudo-relaxed beforehand without a buffer layer.

Shown in Figure 1a is a source wafer 10 according to the invention.

The wafer 10 consists of a supporting substrate 1 and a strained layer 2.

In a first configuration of the supporting substrate 1, the latter is a pseudo-substrate comprising an upper layer made of a crystalline material (not shown in Figure 1), such as a semiconductor material, having an interface with the strained layer 2 and having a first lattice parameter at its interface with the strained layer 2.

The first lattice parameter of the upper layer is advantageously the nominal lattice parameter of the material of which it is composed, so that said material is in a relaxed state.

The upper layer furthermore has a sufficiently large thickness to be able to impose its lattice parameter on the overlying strained layer 2 without the latter having a substantial influence on the crystal structure of the upper layer of the supporting substrate 1.

In a second configuration of the supporting substrate 1, the latter consists of the only crystalline material

having the first lattice parameter.

In another advantageous configuration, the supporting substrate 1 is a single-crystal substrate.

Whatever the configuration chosen for the supporting substrate 1, the latter advantageously has a crystal structure with a low density of structural defects, such as dislocations.

In a first configuration of the strained layer 2, the latter consists only of a single thickness of a crystalline material such as a semiconductor material.

The material chosen to form this strained layer 2 has a second nominal lattice parameter that is substantially different from the first lattice parameter.

The strained layer 2 formed is then elastically strained in compression or in tension by the supporting substrate 1, that is to say it is forced to have a lattice parameter substantially different from the nominal lattice parameter of the material of which it is composed and therefore to have a lattice parameter close to the first lattice parameter.

Advantageously, the material chosen for forming this strained layer 2 has a second nominal lattice parameter that is substantially greater than the first lattice parameter, and is therefore strained in compression.

The strained layer 2 furthermore advantageously has a substantially constant composition of atomic elements.

In a second configuration of the strained layer 2, the latter consists of several thicknesses of materials, each thickness consisting of a crystalline material such as a semiconductor material.

Each thickness of material of the strained layer 2 furthermore advantageously has a substantially constant composition of atomic elements.

The thickness of material of the strained layer 2 directly adjacent to the interface with the supporting substrate 1 then substantially has the same properties as those of a strained layer 2 according to the first configuration.

The advantage of having a small thickness of relaxed material in the strained layer 2 may be at least one of the following:

- it constitutes at least part of the active layer to be formed on the receiving substrate so as to achieve certain material properties;
- it constitutes a stop layer during selective removal of material carried out by selective material removal means, such as selective chemical etching performed by an etching solution, so as especially to preserve an adjacent layer from the material removal;
- it has the possibility of substantially greater removal of material, implemented by selective material removal means such as selective etching, than an adjacent layer, the latter then representing a stop layer during selective material removal, thus being protected from the material removal.

A thickness of relaxed material may also combine several of these functions and may have other functions.

In all cases, the strained layer 2 has a general structure made of strained material, but it may also contain one or more thicknesses of relaxed material which have a cumulative thickness very much less than that of the strained layer 2, so that the latter retains an overall strained state.

Whatever the chosen configuration for the strained layer 2, the latter is advantageously formed on the supporting substrate 1 by crystal growth, such as epitaxial growth using the known techniques such as, for example, the CVD (Chemical Vapour Deposition) and MBE (Molecular Beam Epitaxy) techniques.

To obtain such a strained layer 2 without an excessive number of crystallographic defects, such as for example point defects or extended defects such as dislocations, it is advantageous to choose the crystalline materials of which the supporting substrate 1 and the strained layer 2 (in the vicinity of its interface with the supporting substrate 1) are composed, so that there is a sufficiently small difference between their first and second respective nominal lattice parameters.

For example, this lattice parameter difference is typically between about 0.5% and about 1.5%, but it may also have higher values.

For example, in IV-IV materials, Ge has a nominal lattice parameter about 4.2% greater than that of Si, and therefore SiGe containing 30% Ge has a nominal lattice parameter about 1.15% greater than that of Si.

Moreover, it is preferable for the strained layer 2 to have an approximately constant thickness so that it has substantially constant intrinsic properties and/or can facilitate the future bonding to the receiving substrate 5 (as shown in Figure 1c).

To prevent the strained layer 2 from relaxing or internal stresses of plastic type appearing, the thickness of said strained layer must furthermore remain less than a critical elastic strain thickness.

This critical elastic strain thickness depends principally on the material chosen for the strained

layer 2 and on said difference in lattice parameter with the supporting substrate 1.
A person skilled in the art will refer to the art in order to know the value of the critical elastic strain thickness of the material that he will use for the strained layer 2 formed on the material used for the supporting substrate 1.

Once formed, the strained layer 2 therefore has a lattice parameter substantially similar to that of its growth substrate 1 and therefore has internal elastic strains in compression or in tension.

Referring to Figure 1b, and once the wafer 10 comprising the strained layer 2 has been produced, a region of perturbation 3 is formed in the supporting substrate 1 at a defined depth, a transition layer 4 being bounded substantially by the region of perturbation 3 and the strained layer 2.

A region of perturbation 3 is defined as a region having internal strains capable of forming structural perturbations in the surrounding parts.

This region of perturbation 3 is advantageously formed over practically the entire surface of the supporting substrate 1.

This region of perturbation 3 is advantageously and overall formed parallel to the surface of the supporting substrate 1.

One process for forming such a region of weakness 3 comprises the implantation of atomic species in the supporting substrate 1 at said defined depth, with a defined implantation energy and a defined dose of the atomic species.

In one particular method of implementing the

implantation, the atomic species implanted comprise hydrogen and/or helium.

Such a region of perturbation 3 formed by implantation therefore has internal strains, or even crystallographic defects, exerted by the implanted atomic species on the crystal lattice adjacent to the region of perturbation 3.

These internal strains are therefore capable of creating crystallographic perturbations in the overlying part of the wafer 10.

In particular for this purpose, it is advantageous to carry out a suitable and appropriately parameterized treatment for:

- aiding the appearance of the perturbations in the transition layer 4;
- causing the displacement of these perturbations in the transition layer 4 from the region of weakness 3 towards the interface with the strained layer 2; and
- causing at least relative relaxation of the strained layer 2 after the appearance and the displacement of the perturbations.

The main objective of such a treatment is therefore to cause at least relative relaxation of the strains in the strained layer 2 so as to form a relaxed strained layer 2'.

Thus, a heat treatment is advantageously carried out so as, if it is appropriately parameterized, to supply sufficient energy to cause these structural modifications.

This latter heat treatment must in particular be carried out at a temperature or several temperatures substantially below a critical temperature above which a significant number of implanted atomic species would

be degassed.

Thus, local crystallographic perturbations are created from the internal strains in the region of weakness 3.

Principally for reasons of minimizing elastic energy in the strained layer 2, these perturbations appear in the transition layer 4 in order to be displaced towards the interface between the transition layer 4 and the strained layer 2 along paths defined by particular crystallographic planes.

Upon arriving at the interface between the transition layer 4 and the strained layer 2, these perturbations then cause at least relative relaxation of elastic strains in the strained layer 2, these relaxed strains being mainly lattice mismatch strains between the respective nominal lattice parameters of the material of the strained layer 2 and of the material of the supporting substrate 1.

Such relaxation of elastic strains in the strained layer 2 is mostly accompanied by the appearance of crystalline perturbations in the periphery of the strained layer 2, these possibly being, for example, in the form of dislocations with parameter difference strains at the interface and of atomic steps at the free surface.

However, relaxation of the strained layer 2 may also be accompanied by the appearance of inelastic-type crystal defects in the thickness of said layer, such as traversing dislocations.

Suitable treatments may then be carried out in order to reduce the number of these defects.

For example, a suitable treatment may be carried out which allows the dislocation density to be increased to

between two limiting values, the two limiting values defining a dislocation density range in which at least some of the dislocations are annihilated.

For this purpose, a heat treatment may be carried out which is tailored to the material used, such as that advantageously used to form the perturbations in the abovementioned transition layer 4.

In all cases, what is eventually obtained is a relaxed or pseudo-relaxed layer 2' whose nominal lattice parameter is substantially different from the nominal lattice parameter of the growth substrate 1, without an intermediate buffer layer.

However, one or more thicknesses of elastically strained material may be found in the relaxed strained layer 2'.

These thicknesses of material were comprised in the strained layer 2 before the elastic relaxation of this layer, with a lattice parameter substantially different from the rest of the strained layer 2.

Such thicknesses of material were for example originally relaxed, as described above in the description of the second configuration of the strained layer 2.

During the overall relaxation of the strained layer 2, these thicknesses of material are then subjected to elastic strains exerted by the surrounding material relaxing, and thus become strained.

However, these thicknesses of material must have a cumulative thickness very much less than that of the strained layer 2 so that the latter retains an overall relaxed or pseudo-relaxed state after the elastic relaxation step.

Referring to Figure 1c, a receiving substrate 5 is placed on the surface of the wafer 10 on the side with the relaxed strained layer 2'.

The receiving substrate 5 constitutes a mechanical support sufficiently strong to support the useful layer to be formed and to protect it from possible mechanical stresses coming from the outside.

This receiving substrate 5 may be made, for example, of silicon or quartz or other types of material.

The receiving substrate 5 is attached by bringing it into intimate contact with the wafer 10 and carrying out a bonding operation, in which there is advantageously wafer bonding (molecular adhesion) between the receiving substrate 5 and the wafer 10.

This bonding technique, together with alternatives, is for example described in the document entitled "*Semiconductor Wafer Bonding*" (Science and Technology, Interscience Technology) by Q.Y. Tong and U. Gösele and Wiley.

If necessary, bonding is accompanied by a suitable prior treatment of the respective surfaces to be bonded and/or by supplying thermal energy.

Thus, for example, a heat treatment carried out during bonding allows the strength of the bonds to be increased.

The bonding may also be reinforced by a bonding layer inserted between the wafer 10 and the receiving substrate 5.

This bonding layer is applied to at least one of the two surfaces to be bonded.

Silicon oxide (also called silica or SiO_2) is a material that may be chosen to produce such a bonding layer, it being possible to produce this by oxide deposition or by thermal oxidation or by any other technique.

Before and/or after bonding, a surface finishing operation may be carried out such as, for example, etching, chemical-mechanical polishing CMP, heat treatment or any other smoothing operation.

Once the receiving substrate 5 has been bonded, a portion of the wafer 10 on the opposite side from the relaxed strained layer 2' is removed, the useful layer 6 being the remaining portion of the wafer 10.

Several known techniques for removing material may be employed.

A first material removal technique, called Smart-Cut®, known to those skilled in the art (and a description of which may be found in a number of works dealing with wafer reduction techniques) comprises:

- implantation, before bonding with the receiving substrate 5, of atomic species (such as hydrogen or helium ions) in order to form a region of weakness at a depth close to the implant depth;
- then supply of energy, after bonding, to the region of weakness, such as a heat and/or mechanical treatment, or another supply of energy, in order to bring about detachment of the wafer 10 in two portions in the region of weakness.

Advantageously, the wafer 10 is subjected to a heat treatment during or after implantation in order to further weaken the region of weakness.

In a first method of implementing this material removal, the region of weakness is formed between the

supporting substrate 1 and the relaxed strained layer 2', or in the relaxed strained layer 2'.

In a second method of implementing this material removal, the region of weakness is formed in the supporting substrate 1.

The region of weakness may be formed during or after formation of the perturbation layer 3.

In the particular case of said second method of implementing material removal and in the case of formation of a transition layer 4 by forming a region of perturbation 3, the region of weakness may be formed substantially at the same location as the region of perturbation 3, by carrying out substantially the same techniques, such as implantation of atomic species with a defined energy and with a defined dose of the species.

In this particular case, the region of weakness could be formed substantially at the same time as the region of perturbation 3 is formed.

Before or after implantation, the wafer 10 could be furthermore subjected to a heat treatment having two functions, namely of further weakening the region of weakness and of further relaxing the strained layer 2.

Thus, a region of weakness is formed that would have the double function of weakening the supporting substrate 1 therein and of relaxing the strained layer 2.

A second material removal technique comprises:

- formation in the wafer 10 of a weak interface by forming at least one porous layer by anodization, by implanting atomic species, or by any other pore-forming technique, as described, for example, in document

EP 0 849 788 A2;

- supply of energy to the weak layer, such as a mechanical treatment, or another supply of energy, in order to detach the wafer 10 in two portions within the weak layer.

In a first method of implementing this material removal, the weak layer is formed between the supporting substrate 1 and the relaxed strained layer 2', or within the relaxed strained layer 2'.

In a second method of implementing this material removal, the weak layer is formed in the supporting substrate 1.

To form a weak layer within the supporting substrate 1, the porous layer is advantageously formed on a slice of a single-crystal material, then a second growth of a layer of non-porous crystalline material, having substantially the same lattice parameter as that of the slice, is carried out on the porous layer, and the supporting substrate 1 then consists of the slice, the porous layer and the non-porous Si layer.

The first and second non-limiting material removal techniques allow rapid en bloc removal of a substantial portion of the wafer 10.

These techniques also allow the removed portion of the wafer 10 to be reused in another process as, for example, a process according to the invention.

Thus, a strained layer 2 and possibly a portion of the supporting substrate 1 and/or other layers may be reformed, preferably after the surface of the supporting substrate 1 has been polished.

A third known technique consists in using a chemical and/or chemical-mechanical material removal process.

For example, optionally selective etching of the materials of the donor wafer 10 to be removed may be carried out using a process of the "etch-back" type. This technique consists in etching the wafer 10 "from the rear" that is to say from the free face of the supporting substrate 1, in order in the end to retain that portion of the wafer 10 which is desired to keep on the receiving substrate 5.

Wet etching using etching solutions enabled to the materials to be removed may be carried out.

Dry etching may also be carried out in order to remove the material, such as plasma etching or sputtering.

The etching operation or operations may furthermore be only chemical or electrochemical or photo-electrochemical.

The etching operation or operations may be preceded or followed by mechanical attack of the wafer 10, such as lapping, polishing, mechanical etching or sputtering of atomic species.

The etching operation or operations may be accompanied by mechanical attack, such as polishing optionally combined with the action of mechanical abrasives in a CMP process.

That portion of the wafer 10 that it is desired to remove may thus be entirely removed by just chemical means, or by chemical-mechanical means.

In a first method of implementing this material removal, the etching operation or operations are carried out so as to preserve on the wafer 10 only at least a portion of the relaxed strained layer 2'.

In a second method of implementing this material

removal, the etching operation or operations are carried out so as to preserve on the wafer 10 a portion of the supporting substrate 1 and the relaxed strained layer 2'.

This third technique makes it possible in particular to maintain the high surface quality and the thickness uniformity of the strained layer 2 that were able to be obtained during its crystal growth.

These three techniques are proposed as examples in the present document, but they do not in any way constitute a limitation, the invention extending to any type of technique capable of removing the material from a wafer 10 in accordance with the process according to the invention.

Whatever the material removal technique chosen from these three techniques, or from other known techniques, a surface finishing technique is advantageously carried out on the active layer, such as optionally selective chemical etching, CMP polishing, a heat treatment or any other smoothing operation.

In the particular case in which a portion of the supporting substrate 1 remains after one of these techniques has been carried out, and if it is desired not to retain this residual layer of the supporting substrate 1, it may be advantageous to carry out a finishing step comprising selective etching of the remaining portion of the supporting substrate 1 with respect to the relaxed strained layer 2'.

In the latter particular case, a relaxed strained layer 2' may be obtained which is uniform in thickness and/or has a good surface finish, preventing a substantial number of defects from appearing, such as work-hardened regions, as is sometimes the case with mechanical finishing.

It is then also possible to obtain a portion of the relaxed strained layer 2' which is uniform in thickness and/or has a good surface finish by carrying out selective etching on the relaxed strained layer 2', the latter comprising a stop layer for the etching carried out.

The latter two finishing operations involving selective etching are particularly advantageous if it is desired in the end to obtain very thin relaxed strained layers 2'.

In all cases, what is obtained in the end is a structure 20 comprising the receiving substrate 5, an active layer 6 and optionally an inserted bonding layer.

In a first method of implementing the material removal, only at least a portion of the relaxed strained layer 2' is preserved.

The active layer 6 then consists of at least the portion of the relaxed strained layer 2'.

In a second method of implementing the material removal, only a portion of the supporting substrate 1 and the relaxed strained layer 2' are preserved.

The active layer 6 then consists of the preserved portion of the supporting substrate 1 and the relaxed strained layer 2'.

In this case, the remaining portion of the supporting substrate 1 may in turn be strained, at least in part, by the subjacent relaxed strained layer 2'.

In one particular way of using the structure 20, one or more crystal growth operations may be carried out on the structure 20.

Once the final structure has been achieved, a finishing step may optionally be carried out, such as finishing treatments like, for example, an annealing operation in order to further strengthen the bonding interface between the useful layer 6 and the receiving substrate 5.

In one particular method of using the structure 20, and whatever the structure 20 obtained, one or more epilayers may be grown on the wafer 10.

In the rest of this document, some examples of materials that can constitute the structures in question by implementation of a process according to the invention will be given.

In particular, layers made of materials of the Si and SiGe type will be examined.

As explained above, SiGe containing 30% Ge has a nominal lattice parameter about 1% greater than that of Si.

A strained layer 2 of SiGe having a defined Ge concentration and formed on an Si supporting substrate 1 may be appropriate for implementing a process according to the invention.

Prefered processes for forming useful layer according to the invention are presented in the following examples:

Example 1: with reference to Figure 1a, this relates to the case in which the wafer 10 comprises:

- an Si supporting substrate 1; and
- a strained layer 2 made of SiGe having a defined Ge concentration, with a thickness less than a critical end-of-strain thickness (described above).

The strained SiGe layer 2 has a typical Ge concentration of greater than 15%.

The strained SiGe layer 2 advantageously has a density of defects, such as dislocations, of less than about 10^7 cm^{-2}.

The respective typical thicknesses of a strained layer 2 containing 15% Ge and of a strained layer 2 containing 30% Ge are around 250 nm and around 100 nm, thus remaining below their respective critical end-of-elastic-strain thicknesses.

Referring to Figure 1b, a region of perturbation 3 is formed in the Si supporting substrate 1 by implantation of atomic species such as H or He.

The ranges of H or He implant energies used are typically between 12 and 25 keV.

The implanted H or He doses are typically between 10^{14} and 10^{17} cm^{-2}.

- Thus, for example, for a strained layer 2 containing 15% Ge, it will be preferred to use H for the implant, with a dose of around 3×10^{16} cm^{-2} at an energy of around 25 keV.
- Thus, for example, for a strained layer 2 containing 30% Ge, it will be preferred to use He for the implant, with a dose of around 2.0×10^{16} cm^{-2} at an energy of around 18 keV.

The implantation depths of the atomic species are typically between 50 nm and 100 nm.

The formation of the region of perturbation 3 is then followed by a suitable heat treatment, in particular to displace perturbations in the transition layer 4 and cause dislocations in the relaxed strain layer 2' to

disappear.

The heat treatment is carried out in an inert atmosphere.

However, the heat treatment may be carried out in another atmosphere such as, for example, an oxidizing atmosphere.

Thus, a particular heat treatment to be carried out for this type of wafer 10 is performed at temperatures typically between 600°C and 1000°C for a typical time ranging from about 5 minutes to about 15 minutes.

For more details as regards such experimental techniques, reference will be made to the studies carried out by B. Holländer et al, especially in the document entitled "*Strain relaxation of pseudomorphic $Si_{1-x}Ge_x$ / Si(100) heterostructures after hydrogen or helium ion implantation for virtual substrate fabrication*" (in Nuclear and Instruments and Methods in Physics Research B 175-177 (2001) 357 - 367).

In another case of forming a region of perturbation 3 according to the present invention, hydrogen or helium is implanted with a dose of about 10^{17} cm^{-2}.

This particular dose is in accordance with the formation of a region of weakness using a process of the Smart-Cut® type and allows both a region of perturbation 3 and a region of weakness to be formed.

This region of weakness will thus have two functions, namely of causing internal strains capable of forming crystalline perturbations in the overlying transition layer 4 and of being sufficiently weak to detach the wafer 10 in two portions after supplying energy.

In one particular embodiment, a subsequent heat treatment will have the two functions of relaxing the

strains in the strained layer 2 and of further weakening the region of weakness.

Whatever the particular method of implementation chosen to form the transition layer 4, the SiGe strained layer 2 relaxes, at least partly, in order to form an SiGe relaxed strained layer 2'.

Referring to Figure 1c, the receiving substrate 5 attached to the wafer 10 may consist of any material, such as silicon or quartz.

An SiO_2 bonding layer is advantageously inserted between the relaxed strained layer 2' and the receiving substrate 5, thereby making it possible in particular to produce in the end (with reference to Figure 1d) a structure 20 of the SGOI or Si/SGOI type, the insulator in question in this structure 20 then being the SiO_2 layer.

Referring to Figure 1d, one or more known techniques for removing material may be carried out.

In particular, selective etching of the Si may be carried out using etching solutions having substantial selectivity with respect to SiGe, such as solutions comprising at least one of the following compounds: KOH, NH_4OH (ammonium hydroxide), TMAH, EDP or HNO_3 or solutions currently under study, that combine agents such as HNO_3, HNO_2, H_2O_2, HF, H_2SO_4, H_2SO_2, CH_3COOH and H_2O, as explained in the document WO 99/53539 on page 9.

In a first situation, the latter selective etching makes it possible to remove a remaining portion of the supporting substrate 1 to be removed with respect to the relaxed strained layer 2' to be retained on the structure 2, the useful layer 6 then consisting, after etching, of the relaxed strained layer 2'.

In a second situation, an Si etching stop layer is placed in the supporting substrate 1, making it possible to preserve, from selective chemical etching of the etch-back type, an Si layer overlying to the stop layer, the active layer 6 then comprising in this case the relaxed strained layer 2' and the Si layer overlying to the stop layer.

The stop layer may for example, be made of SiGe and the selective chemical etching in question employs one of the above etching solutions.

Referring to Figure 1d, a structure 20 comprising the receiving substrate 5 and an active layer 6 is obtained.

The active layer 6 comprises at least one portion of the SiGe relaxed strained layer 2' and optionally an Si layer, remaining portion of the supporting substrate 1, depending on the method of removal employed.

Example 2: with reference to Figure 2, this example relates to a wafer 10 substantially the same as that of Example 1, but furthermore including a substantially relaxed Si layer on the strained SiGe layer.

The strained layer 2 therefore consists of the strained SiGe layer 2A and the relaxed Si layer 2B.

This strained layer 2 has a thickness of less than the critical thickness of the SiGe in question - above this thickness the SiGe relaxes.

The strained layer 2A has substantially the same characteristics as the strained SiGe layer 2 of Example 1.

The relaxed Si layer 2B has a thickness very much less

than that of the thickness of the entire strained layer 2, so that the strained layer 2 retains an overall strained structural property.

The relaxed Si layer 2B has a thickness of about a few tens of nanometres.

The implementation of the removal process is then substantially the same as that of Example 1.

The creation of a transition layer 4 and an additional advantageous heat treatment, that are substantially identical to those of Example 1, have the effect of:

- elastically relaxing the strained layer 2A in order to form a relaxed strained layer 2A' (not shown), and
- elastically straining the relaxed layer 2B in order to form a strained relaxed layer 2B' (not shown) the latter then having a lattice parameter close to that of the subjacent relaxed SiGe.

After the wafer 10 has been bonded to a receiving substrate 5 at the strained relaxed layer 2B', with or without an intermediate bonding layer, material may be removed using one or more of the known techniques described above.

In a first method of implementing the material removal, it is desired to retain at least a portion of the relaxed strained layer 2A', and the strained Si layer 2B', and the material removal is then substantially the same as that described in Example 1.

What is obtained in the end is a structure 20 (like that shown in Figure 1d) comprising the receiving substrate 5 and an active layer 6, the active layer 6 consisting of the strained Si layer 2B' and of at least one portion of the relaxed SiGe layer 2A' (and optionally of an Si layer, or the remaining portion of the supporting substrate 1, depending on the removal method employed).

In a second method of implementing the removal process, it is desired to retain only at least a portion of the strained Si layer 2B', and the material removal is then substantially identical to that described in Example 1 with furthermore an additional step of removing the relaxed SiGe layer 2A'.

For this purpose, selective etching of the SiGe may be carried out using solutions for the selective etching of SiGe with respect to Si, such as a solution comprising $HF:H_2O_2:CH_3COOH$ (selectivity of about 1:1000).

In this second method of implementing the process, the relaxed SiGe layer 2A' thus becomes sacrificial.

Such a sacrifice of the relaxed SiGe layer 2A' involves the disappearance of structural defects, such as dislocations with parameter difference strains, which may be confined on the surface and appear, before bonding, in the vicinity of the interface with the transition layer 4 after propagation of the perturbations in the transition layer 4.

The relaxed SiGe layer 2A' thus preserves the strained Si layer 2B' from the possible structural defects resulting from the particular method of relaxation employed in the process according to the invention.

This sacrificial technique is therefore particularly suited for obtaining in the end a strained Si layer 2B' with few structural defects.

What is obtained in the end is a structure 20 (like that shown in Figure 1d) comprising the receiving substrate 5 and an active layer 6, the active layer 6 consisting of the strained Si layer 2B'.

Example 3: with reference to Figure 3, this example relates to a wafer 10 substantially the same as that of Example 2, furthermore including a substantially strained SiGe layer on the relaxed Si layer.

The strained layer 2 then consists of the strained SiGe layer 2A, the relaxed Si layer 2B and the strained SiGe layer 2C.

This strained layer 2 has a smaller thickness than the critical thickness of the SiGe in question, above which the SiGe relaxes.

The strained layer 2A has substantially the same characteristics as the strained SiGe layer 2 of Example 1.

It will be advantageous to choose a thickness of the layer 2A greater than or equal to the typical thickness at which structural defects appearing near the interface with the transition layer 4, after propagation of the perturbations in the transition layer 4, are likely to be confined therein.

Such a strained SiGe layer 2A will thus preserve the relaxed Si layer 2B and the strained SiGe layer 2C from any structural defects during overall relaxation of the strained layer 2.

This sacrificial technique is therefore particularly suitable for obtaining in the end an Si layer 2B with few structural defects.

The relaxed Si layer 2B has a thickness very much less than the thickness of the entire strained layer 2, so that the strained layer 2 retains an overall strained structural property.

The relaxed Si layer 2B has a thickness of around a few

tens of nanometres.

The strained SiGe layer 2C has substantially the same characteristics as the strained SiGe layer 2A.

However, the strained SiGe layer 2C is advantageously thicker than the strained SiGe layer 2A.

The strained SiGe layer 2C represents, in one particular situation, the major portion of the thickness of the strained layer 2.

The implementation of the removal process is then substantially identical to that of Example 2.

The creation of a transition layer 4 and an additional advantageous heat treatment, which are identical to those of Example 1, have the effect of:

- elastically relaxing the strained layer 2A in order to form a relaxed strained layer 2A' (not shown);
- elastically straining the relaxed layer 2B in order to form a strained relaxed layer 2B' (not shown), the latter then having a lattice parameter close to that of the subjacent relaxed SiGe; and
- elastically relaxing the strained layer 2C in order to form a relaxed strained layer 2C' (not shown).

After the wafer 10 has been bonded to a receiving substrate 5 at the relaxed strained layer 2C', with or without an intermediate bonding layer, material may be removed using one or more of the known techniques described above.

In a first method of implementing the material removal, it is desired to retain at least a portion of the relaxed strained layer 2A', the strained Si layer 2B' and the relaxed SiGe layer 2C', and the material removal is then substantially the same as that described in Example 1.

What is obtained in the end is a structure 20 (like that shown in Figure 1d) comprising the receiving substrate 5 and an active layer 6, the active layer 6 consisting of the relaxed SiGe layer 2C', the strained Si layer 2B' and of at least one portion of the relaxed SiGe layer 2A' (and optionally of an Si layer, or the remaining portion of the supporting substrate 1, depending on the removal method employed).

In a second method of implementing the material removal, it is desired to preserve only at least a portion of the strained Si layer 2B' and the relaxed SiGe layer 2C', the material removal then being substantially identical to the second method of implementing the material removal of Example 2.

What is obtained in the end is a structure 20 (like that shown in Figure 1d) comprising the receiving substrate 5 and an active layer 6, the active layer 6 consisting of at least the portion of the strained Si layer 2B' and of the relaxed SiGe layer 2C'.

In a third method of implementing the process, it is desired to retain only at least a portion of the relaxed SiGe layer 2C', and the material removal is then substantially the same as that described in the second method of implementation above, with furthermore an additional step of removing the strained Si layer 2B'.

For this purpose, selective etching of the strained Si 2B' may be carried out using solutions comprising at least one of the following compounds: KOH, NH_4OH (ammonium hydroxide), TMAH, EDP or HNO_3 or solutions currently under study that combine agents such as HNO_3, HNO_2, H_2O_2, HF, H_2SO_4, H_2SO_2, CH_3COOH and H_2O.

Since the relaxed SiGe layer 2C' is an etching stop

layer, this method makes it possible in the end to obtain a layer particularly uniform in thickness with a low surface roughness.

Thus, it is possible in particular to have a layer of very small thickness while maintaining good layer quality.

What is obtained in the end is a structure 20 (like that shown in Figure 1d) comprising the receiving substrate 5 and an active layer 6, the active layer 6 constituting the relaxed SiGe layer 2C'.

In one particular method of using the structure 20, and whatever the structure 20 obtained, one or more epilayers may be grown on the wafer 10, such as the epitaxial growth of an SiGe layer or of a strained Si layer, or other epilayers consisting of an alternating succession of SiGe layers or strained Si layers in order to form a multilayer structure.

In the semiconductor layers presented in this document, other constituents may be added thereto, such as carbon with a carbon concentration in the layer in question substantially less than or equal to 50% or more particularly with a concentration of less than or equal to 5%.

The present invention is not limited to a strained SiGe layer 2 and an Si supporting substrate 1, but extends also to other materials, such as materials of the III-V or II-VI atomic family (of the binary, ternary or quaternary type or having a higher degree), that can be employed using a process according to the present invention.

Nor are the structures finally obtained after take-off limited to structures of the SGOI, SOI or Si/SGOI type.

CLAIMS

1. Process for forming a useful layer (6) from a wafer (10), the wafer (10) comprising a supporting substrate (1) and a strained layer (2) chosen respectively from crystalline materials for an application in microelectronics, in optics or in optoelectronics, characterized in that it comprises the following steps:

(a) formation in the supporting substrate (1) of a region of perturbation (3) at a defined depth capable of forming structural perturbations;

(b) supply of energy to cause at least relative relaxation of the elastic strains in the strained layer (2); and

(c) removal of a portion of the wafer (10) on the opposite side to the relaxed strained layer (2'), the useful layer (6) being the remaining portion of the wafer (10).

2. Process for forming a useful layer (6) according to the preceding claim, characterized in that the at least relative relaxation of the strained layer (2) during step (b) takes place across a transition layer (4) separating the region of perturbation (3) from the strained layer (2).

3. Process for forming a useful layer (6) according to either of the preceding claims, characterized in that the region of perturbation (3) is formed by implantation of atomic species.

4. Process for forming a useful layer (6) according to the preceding claim, characterized in that the atomic species implanted comprise, at least partly, hydrogen and/or helium.

5. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that

the energy supplied during step (b) comprises thermal energy so as to further favour the relaxation of the strains in the strained layer (2).

6. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that it furthermore includes, before step (c), a step of bonding a receiving substrate (5) to the wafer (10) on the side with the strained layer (2).

7. Process for forming a useful layer (6) according to the preceding claim, characterized in that the bonding step is preceded by the application of a bonding layer to at least one of the two faces to be bonded.

8. Process for forming a useful layer (6) according to the preceding claim, characterized in that the bonding layer is made of silica.

9. Process for forming a useful layer (6) according to one of the three preceding claims, characterized in that it furthermore includes the implementation of a finishing step carried out on the surface of at least one of the two faces to be bonded.

10. Process for forming a useful layer (6) according to one of the four preceding claims, characterized in that it furthermore includes a heat treatment in order to strengthen the bonds.

11. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that:

- before step (c), it comprises the formation of a region of weakness (3) in the supporting substrate (1); and
- step (c) comprises the supply of energy into the region of weakness in order to detach the useful layer (6) from the donor wafer (10).

12. Process for forming a useful layer (6) according to the preceding claim, characterized in that the region of weakness is formed by implantation of atomic species.

13. Process for forming a useful layer (6) according to the preceding claim, characterized in that the atomic species implanted comprise, at least partly, hydrogen and/or helium.

14. Process for forming a useful layer (6) according to either of the two preceding claims, characterized in that the region of weakness and the region of perturbation (3) are located substantially at the same point in the wafer (10).

15. Process for forming a useful layer (6) according to the preceding claim, characterized in that the region of weakness and the region of perturbation (3) are formed substantially at the same time and by the same means for forming the regions.

16. Process for forming a useful layer (6) according to Claim 11, characterized in that the region of weakness is formed by porosification of a layer in the wafer (10).

17. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that step (c) comprises the chemical etching of at least a portion of the wafer (10) to be removed.

18. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that step (c) comprises the implementation of selective chemical etching of a portion of the supporting substrate (1) adjacent to the relaxed strained layer (2'), the relaxed strained layer (2') forming a stop layer for this etching.

19. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that the relaxed strained layer (2') comprises a chemical etching stop layer and in that step (c) comprises the implementation of selective chemical etching of the relaxed strained layer (2') in order to remove the portion overlying to the stop layer.

20. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that the useful layer (6) consists of at least a portion of the relaxed strained layer (2').

21. Process for forming a useful layer (6) according to one of Claims 1 to 17, characterized in that the useful layer (6) consists of the relaxed strained layer (2') and a portion of the supporting substrate (1) remaining after step (c).

22. Process for forming a useful layer (6) according to the preceding claim, characterized in that the remaining layer of the supporting substrate (1) is strained by the relaxed strained layer (2).

23. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that it includes, after step (c), a finishing step carried out on the surface of the useful layer (6).

24. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that it includes, after step (c), the formation of at least one layer on the useful layer (6).

25. Process for forming a useful layer (6) according to either of the two preceding claims, characterized in that at least one thin layer formed on the useful layer (6) has its lattice parameter strained by the relaxed strained layer (2').

26 Process for forming a useful layer (6) according to one of the preceding claims, characterized in that:

- the supporting substrate (1) is made of silicon;
- the strained layer (2) is made of silicon-germanium.

27. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that:

- the supporting substrate (1) is made of silicon;
- the strained layer (2) consists in succession of:
  - ✓ a thickness of strained silicon-germanium (2A);
  - ✓ a thickness of relaxed silicon (2B).

28. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that:

- the supporting substrate (1) is made of silicon;
- the strained layer (2) consists in succession of:
  - ✓ a thickness of strained silicon-germanium (2A);
  - ✓ a thickness of relaxed silicon (2B);
  - ✓ a thickness of strained silicon-germanium (2C).

29. Process for forming a useful layer (6) according to either of the two preceding claims, characterized in that step (c) comprises the removal of the thickness of strained silicon-germanium (2A) adjacent to the supporting substrate (1) and relaxed during implementation of step (a).

30. Process for forming a useful layer (6) according to either of the two preceding claims, characterized in that step (c) comprises the removal of the thickness of

relaxed silicon (2B) strained during implementation of step (b).

31. Process for forming a useful layer (6) according to one of the five preceding claims, characterized in that at least one thin layer formed on the useful layer (6) comprises at least one of the following materials:

- relaxed or pseudo-relaxed silicon-germanium with a germanium concentration approximately equal to that of the strained layer (2);
- silicon at least partly strained to have a lattice parameter close to the lattice parameter of the relaxed strained layer (2').

32. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that the receiving substrate (5) is made of silicon or quartz.

33. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that at least one of the layers employed during the process furthermore includes carbon with a carbon concentration substantially less than or equal to 50%.

34. Process for forming a useful layer (6) according to one of the preceding claims, characterized in that at least one of the layers employed during this process furthermore includes carbon with a carbon concentration substantially less than or equal to 5%.

35. Application of a process for forming a useful layer (6) according to one of the preceding claims to the production of a semiconductor-on-insulator structure, the thickness of semiconductor of the structure comprising the useful layer formed.

36. Wafer (10) intended to be used in a process for forming a useful layer (6) according to one of Claims 1

to 34, characterized in that it comprises a supporting substrate (1) having a first lattice parameter and an overall relaxed or pseudo-relaxed layer (2') having a second lattice parameter and in that it does not include a buffer layer.

37. Wafer (10) according to the preceding claim, characterized in that it furthermore includes a region of perturbation (3) in the supporting substrate (1).

38. Wafer (10) according to either of the two preceding claims, characterized in that it furthermore includes a region of weakness.

39. Structure comprising a wafer (10) according to one of the three preceding claims and a receiving substrate (5).