INDIRECT BONDING WITH DISAPPEARANCE OF THE BONDING LAYER

The field of application of the invention is that of methods of producing semiconductor on insulator (SeOI) structures which serve as substrates for electronics, optics, and optoelectronics.

One non-limiting application of the invention relates to the production of a SeOI structure by indirect bonding of a layer of semiconductor material to a layer of thermal oxide present on the surface of a support substrate.

As it will be described in more detail below, the term "indirect bonding" means bonding employing a bonding layer intercalated between two layers of materials which are to be bonded together.

The use of a bonding layer is of particular advantage when it is difficult to achieve direct bonding of certain semiconductor materials to a layer (for example an oxide layer).

This difficulty is observed in particular when, in order to produce a silicon-germanium on insulator (SGOI) structure, a layer of silicon-germanium SiGe is to be bonded directly to a layer of oxide on the surface of a support substrate.

It should be noted that this difficulty is all the more pronounced when the concentration of germanium in the SiGe layer is high.

In order to carry out direct bonding of a SiGe layer to a support substrate, several methods have been proposed for treating the surfaces to be bonded prior to bonding. In particular, cleaning of the surfaces to be bonded together is generally carried out, before bonding, for controlling the different parameters (such as roughness, particulate contamination) likely to prevent the adhesion of the surfaces.

As an example, a method known as "hydrophobic bonding" may be mentioned, in which method the surfaces to be bonded are prepared (for example by immersing them in a HF chemical cleaning bath) prior to bonding in order to render them hydrophobic.

However, that preparation tends to cause severe particulate contamination of the surfaces, with the particular consequence of generating defects during bonding.

A hydrophilic bonding method has also been proposed in which the surface of the SiGe layer to be bonded is treated to render it hydrophilic prior to bringing it into contact either with a hydrophilic silicon surface or with a surface of silicon oxide SiO_2.

One of the best known treatments for rendering a layer hydrophilic consists in immersing the layer in a chemical SC1 type solution ($NH_4OH/H_2O_2/H_2O$).

However, that solution etches the SiGe layer and tends to increase its roughness, resulting in a bond of unsatisfactory quality.

It should be noted that the etching rate varies exponentially as a function of the concentration of germanium in the SiGe layer.

For that reason, although controlled etching in a SiGe layer having a low concentration of germanium (for example 20%) is possible (and thus bonding may be envisaged), controlled etching in a SiGe layer having a high concentration of germanium (for example 50%) is difficult.

Finally, while hydrophilic bonding of a SiGe layer having a low concentration of germanium (for example 20%) may be carried out in a relatively satisfactory manner, hydrophilic bonding of a SiGe layer having a high concentration of germanium (for example 50%) cannot be carried out in a satisfactory manner.

More precisely, surface treatment methods for directly bonding a SiGe layer to a support substrate of Si or SiO_2 has disadvantages such that bonding quality, for example, is generally not acceptable as regards specifications in force in the fields of application of the invention.

Further, good quality bonding is even more difficult to achieve when the germanium concentration in the SiGe layer to be transferred is high.

It should be noted that the disadvantages of direct bonding mentioned above regarding bonding of a SiGe layer may also be encountered in the context of direct bonding of layers produced in other materials.

Thus, it appears to be particularly advantageous to coat a layer which cannot be bonded directly to the surface of a support substrate (for example a Ge layer) with a layer called a bonding layer (for example a layer of oxide or a layer of silicon) which may be bonded directly to the surface of the support substrate (in particular because it is possible to perform a surface treatment of this bonding layer in order to clean it so that a bonding of satisfactory quality can be achieved).

Thus, when the bonding layer is brought into contact with the surface of the support substrate, advantage is taken of the good bonding properties of the cleaned bonding layer and good quality bonding may be achieved.

Indirect bonding, then, is bonding via a bonding layer as opposed to the direct bonding methods mentioned above.

In order to carry out indirect bonding, advantage may be taken of the good bonding properties of the following, for example:

- a layer of silicon on a layer of the oxide SiO_2 on the surface of a support substrate;
- a layer of oxide on
  - a layer of the oxide SiO_2 on the surface of a support substrate; or
  - a silicon support substrate.

Returning to the example of indirect bonding of a layer of SiGe to a support substrate the surface of which may, for example, be formed from Si or SiO_2, in a first technique, it may be envisaged that a layer of oxide may be created directly on a layer of SiGe by oxidizing said SiGe layer.

However, during oxidation of a SiGe layer, the germanium present in said layer is pushed into regions thereof which are distant from the oxide layer being formed. Thus, germanium is observed to be segregated at the SiGe/oxide interface.

Finally, a zone is formed opposite the oxide in which the overall concentration of germanium increases. Thus, the concentration of germanium is no longer uniform through the SiGe layer.

Although the germanium segregation phenomenon may be minimized, in particular by carrying out the oxidation at low temperatures, the oxide formed is thermally unstable.

Thus, that first technique cannot be used when forming a good quality SGOI structure.

Instead of having recourse to oxidizing a layer of SiGe to obtain a bonding layer, a further known method of indirect bonding consists in directly depositing a layer of oxide onto a layer of SiGe. The deposited oxide layer must then be polished prior to bonding to a silicon support substrate.

However, the layer of oxide deposited on the SiGe layer then constitutes the buried oxide layer of the SGOI structure obtained, and this leads to disadvantages.

The density of that layer of oxide and its electrical performance may prove to be insufficient (in particular in comparison with the density and performance of a thermal oxide) for producing an oxide/semiconductor interface that satisfies the specifications in force in the semiconductor industry.

Further, the use of a deposited oxide may generally result in poor homogeneity of the thickness of the buried oxide layer in the SGOI structure.

Still further, said lack of homogeneity may prove to be incompatible with the intended use of SeOI structures in the semiconductor industry.

Yet still further, depositing said oxide layer may cause contamination that may result in electrical defects.

A further technique for indirectly bonding a layer consists in epitaxially growing a layer of strained silicon on the surface of a layer of SiGe. That silicon layer is then completely oxidized to substitute it for a layer of silicon oxide SiO_2 and then to carry out oxide/oxide bonding with an oxidized silicon support substrate.

Total oxidation of the silicon layer epitaxially grown on the SiGe layer effectively causes the formation of an oxide layer on the surface of the structure to be bonded.

However, stopping the oxidation front of that epitaxially grown Si layer exactly at the interface between the epitaxially grown silicon layer and the SiGe layer is very difficult to accomplish.

The oxidation front is thus generally stopped after the Si/SiGe interface (this is termed "overoxidation").

In such a case, SiGe is oxidized and the composite oxide $Si_yGe_tO_2$ (y and t representing the respective concentrations of silicon and germanium in said composite oxide) is then formed.

The oxide/SiGe interface is then susceptible of constituting an electrical trap for charge carriers. Finally, its quality is not satisfactory.

Finally, while such a technique allows good oxide/oxide bonding, the effects of the difficulty of controlling the oxidation front (in particular a poor quality oxide/SiGe interface in the case of overoxidation) are not desirable.

One aim of the invention is to produce SeOI structures, overcoming the limitations discussed above.

More specifically, in one particular aspect, the invention aims to enable indirect bonding of a layer of semi conductive material to a support substrate via a bonding layer, which bonding to the support substrate is properly achieved, without recourse to total oxidation of the bonding layer, thereby overcoming the problem of stopping the oxidation front.

To this end, the invention provides a method of producing a structure comprising a thin layer of semiconductor material on a support substrate, said thin layer being obtained from a donor substrate comprising an upper layer of semiconductor material, the method being characterized in that it comprises the steps consisting in:

- forming on said upper layer a bonding layer of a material that accepts diffusion of an element of the material of the upper layer;
- cleaning said bonding layer for mastering its bonding adhesion;
- bonding the donor substrate, from the side of the bonding layer previously formed on the upper layer and cleaned, to the support substrate; and
- diffusing said element from the upper layer into the bonding layer to homogenize the concentration of said element in the bonding layer and said upper layer, to constitute said thin layer of the structure with said bonding layer and said upper layer.

Preferred but non-limiting aspects of the method of the first aspect of the invention are as follows:

- during the diffusion step, the bonding layer disappears by blending into the upper layer to form the thin layer of the structure;
- following bonding and prior to diffusion, the method may include a thinning step aimed at removing a portion of the donor substrate to retain only a portion of its upper layer, so as to obtain an intermediate structure comprising the support substrate, the bonding layer and a thin layer formed by the remainder of the upper layer;
- thinning may be carried out by detachment from the donor substrate at a zone of weakness formed prior to bonding in the thickness of said upper layer;
- the zone of weakness may be formed by implanting species into the upper layer;
- a protective layer may be deposited on the bonding layer prior to implantation, said protective layer being removed prior to bonding;
- the thinning step may comprise at least one etching step;
- the diffusion step may be carried out by applying a heat treatment to the intermediate structure obtained after thinning;
- the diffusion step may be carried out during a heat treatment for stabilizing the bonding interface of the structure obtained after thinning;
- the heat treatment may be carried out between 1000°C and 1100°C for about two hours;
- when the upper layer is SiGe, the diffusion step consists in diffusing the element Ge from said upper layer into the bonding layer;
- the step of depositing the bonding layer may comprise depositing a film of strained silicon Si on said SiGe upper layer;

- the strained silicon film may be deposited by epitaxial growth;
- the thickness of the epitaxially grown strained Si film is preferably about 5 nanometers (nm);
- bonding may be carried out on an oxidized support substrate to form a good quality Si/oxide bond;
- following formation of the strained monocrystalline Si film and prior to bonding, a partial thermal oxidation step may be carried out to form a layer of thermal oxide on the surface of said strained Si film;
- bonding may be carried out directly on an oxidized support substrate to produce a good quality oxide/oxide bond;
- bonding may also be carried out directly onto a silicon support substrate to produce a good quality oxide/Si bond;
- the cleaning of the bonding layer may be performed with a SC1 type solution;
- the step of forming the bonding layer may also comprise forming, on said SiGe upper layer, a film of SiGe with a germanium concentration such that direct bonding of said SiGe film to a layer of oxide is mastered;
- the concentration of germanium in said SiGe film is less than 20%, for example;
- bonding may be carried out directly to an oxidized support substrate so that a good quality SiGe/oxide bond is achieved;
- during the diffusion step, the element Ge diffuses into the bonding layer (or at least into the non-oxidized portion of the bonding layer when a step of partially oxidizing said bonding layer has been carried out prior to bonding) so that a layer with a homogeneous concentration of Ge is obtained by assimilation of said bonding layer with said SiGe upper layer;
- the cleaning step of a SiGe bonding layer may be performed according to a RCA type treatment;
- the cleaning step may also comprise the cleaning of the face of the support substrate which is to be bonded to the bonding layer.

In a more general aspect, the invention also provides a method of bonding together a first and a second wafer of semiconductor material, the first wafer comprising an upper layer and the second wafer comprising a free face, characterized in that it comprises the steps of:

- forming, on the upper layer of the first wafer, a bonding layer of a material that accepts diffusion of an element of the material of said upper layer;
- cleaning said bonding layer for mastering its bonding adhesion;

- bonding the first wafer, from the side of the bonding layer previously formed on the upper layer and cleaned, to the free face of the second wafer; and
- diffusing said element of the upper layer into the bonding layer to homogenize the concentration of said element in the bonding layer and said upper layer, said bonding layer disappearing by blending with said upper layer so that said wafers are bonded together, the upper layer of the first wafer being connected to the free face of the second wafer.

Further characteristics, aims and advantages of the invention become apparent from the following detailed description, made with reference to the accompanying drawings given by way of non-limiting examples and in which:

- Figure 1 (Figures 1a to 1e) are diagrams showing the various steps of a method according to a possible embodiment of the invention;
- Figures 2a to 2f show an implementation of the method of the invention in the context of a SMARTCUT® type transfer method of indirect bonding of a layer of relaxed SiGe to an oxidized silicon support substrate and producing a SGOI structure.

The invention relates in general to bonding an upper layer formed on a donor substrate onto a substrate support.

More particularly, the invention relates to an upper layer formed from a material which cannot be bonded directly onto the support substrate.

Bonding is thus carried out indirectly via a bonding layer which is formed on the upper layer.

In general, the bonding layer used in the context of the invention is a layer of a material:

- for which bonding to the support substrate is mastered;
- and which accepts diffusion of an element of the material composing the upper layer.

It has to be noted that the bonding of a layer is regarded as being mastered when a cleaning of this layer can be performed, before bonding, during a surface treatment step, so as to control the parameters (such as roughness, hydrophily, particulate contamination) which are likely to prevent the adhesion of the surface.

Figures 1a to 1e are diagrams showing the various steps in the method according to the invention.

Referring to Figure 1a, a donor substrate 10 is used which comprises a lower layer 1 and an upper layer 2.

Said upper layer 2 is typically formed from a semiconductive material which cannot be directly bonded in a satisfactory manner to the free surface 4 of a support substrate 20 (also shown in Figure 1a).

Referring to Figure 1b, the method of the invention comprises a step of forming, on the upper layer 2 of the donor substrate 10, a bonding layer 3 with the characteristics mentioned above.

The method according to the invention comprises, before bonding, a cleaning step (for example a hydrophilic treatment) of the surface of the bonding layer 3, so as to ensure in particular a good bonding strength, and thus to master the bonding of the bonding layer 3 with the free face 4 of the substrate support.

Of course, one preferably carries out a cleaning of each of the surfaces to be bonded together (bonding layer 3 and free face 4 of the substrate support). An identical cleaning treatment is thus performed on both surfaces to be bonded together.

Referring to Figure 1c, the method of the invention comprises a step of bonding the structure comprising the donor substrate 10 and the bonding layer 3 to the support substrate 20, the bonding layer 3 being brought into intimate contact with the free face 4 of said support substrate 20.

Referring to Figures 1c and 1d, the method of the invention can include a thinning step to remove a portion of the donor substrate 10 to retain only a portion of its upper layer 2 and thus obtain an intermediate structure comprising the remainder of the upper layer (i.e. a layer 2' in the same material as the upper layer 2), the bonding layer 3 and the support substrate 20.

Finally, the method of the invention comprises a step aimed at diffusing into the bonding layer 3 an element of the material of the layer 2' to cause said bonding layer 3 to disappear by assimilating it with said thin layer.

A homogeneous thin layer 2" is thus formed on the surface of the support substrate 20.

Note that the material of said thin layer 2" is derived from the materials of the layer 2' and the bonding layer 3.

More precisely, because of the diffusion that has occurred between the material of the layer 2' and that of the bonding layer 3, said two layers constitute a single thin layer 2" the material of which is homogeneous.

This aspect is described further below with reference to an implementation of the invention.

Note that to cause the bonding layer 3 to "disappear" into the layer 2' to form the thin layer 2", the thickness of said bonding layer 3 is adjusted to allow it to reduce to a sufficient extent.

Finally, a structure is obtained which comprises the thin layer 2" on the donor substrate 20.

The characteristics of the material of the thin layer 2" resemble those of the material of the upper layer 2 of the starting donor substrate 10.

The bonding layer 3 used has disappeared and no longer figures in the final structure.

One non-limiting application of the invention relates to bonding any structure comprising a SiGe upper layer onto a support substrate (for example made of silicon).

A structure comprising a SiGe upper layer may include an upper layer of strained SiGe.

In that case, for example, a donor substrate is used that comprises a wafer of monocrystalline silicon and a SiGe upper layer, said SiGe upper layer being strained by the subjacent Si wafer. It should be noted that in such a case, a bonding layer of Si formed on said upper layer of strained SiGe has the same lattice parameter as the Si wafer and is thus not strained.

A structure comprising a SiGe upper layer can also comprise an upper layer of relaxed SiGe.

In that case, a donor substrate comprising, for example, a wafer of monocrystalline silicon is used on which said upper layer of relaxed SiGe is produced via a buffer layer in which the lattice parameter changes despite the difference in lattice parameters existing between the two materials, Si and SiGe.

The buffer layer intercalated between the Si wafer and the layer of relaxed SiGe is generally formed from SiGe, with a proportion of germanium that progressively increases in quantity from the Si wafer towards the upper layer of relaxed SiGe.

A further example of the structure relates to a structure comprising a layer of SiGe on which a film of Si has been grown, a relatively thin layer of SiGe finally being on the surface of said Si film.

In particular, said film of Si constitutes an etch-stop layer when carrying out selective etching of SiGe over Si.

Clearly, the invention also encompasses more complex structures comprising a SiGe upper layer and one or more etch-stop layers.

The silicon support substrate can comprise at the surface a layer of silicon oxide SiO_2 obtained conventionally by thermal oxidation of said Si support substrate.

➢ In a first embodiment of the invention, the bonding layer can be a layer of silicon.

The layer of Si is preferably formed from monocrystalline Si, but it may also be formed from polycrystalline or amorphous Si.

In a variation of said first embodiment, prior to bonding, partial oxidation of the Si layer is carried out to form a layer of thermal oxide on the surface of said Si layer.

In the context of said variation, the layer of oxide SiO_2 formed by oxidation of the Si layer acts as the bonding layer.

Since oxidation is only partial, it should be noted that the oxidation front can be stopped before it reaches the SiGe layer subjacent to said bonding layer, which overcomes the limitations mentioned above.

In said first implementation, advantage is taken of the bonding properties of:

- a Si bonding layer on a SiO_2 layer of the surface of a Si support substrate (if the Si support substrate is oxidized);

and in the context of the variation mentioned above:

- a bonding layer formed from SiO_2 on a SiO_2 layer of on the surface of a Si support substrate (if the Si support substrate is oxidized);
- a bonding layer of SiO_2 on a Si support substrate (if the Si support substrate is not oxidized).

➢ In a second embodiment of the invention, the bonding layer can be a layer of silicon-germanium with a germanium concentration such that its bonding to an oxidized Si substrate can be mastered (i.e. as mentioned above, for example, a SiGe layer with a low concentration of germanium, typically less than 20%). In such a case, a SiGe layer acts as a bonding layer in that it is possible to master its bonding, in particular in that it is possible to perform a surface treatment of the SiGe layer so as to clean it and hence to ensure that a satisfactory bonding strength can be achieved.

Figures 2a to 2f show an example of the invention for indirect bonding of a layer of relaxed SiGe to a support substrate of oxidized silicon and the production of a SGOI structure.

More particularly, this embodiment of the invention is carried out within the context of a SMARTCUT® type transfer method.

Further details regarding the SMARTCUT® method can be found in the document "Silicon-on-Insulator Technology: Materials to VLSI, 2nd Edition" by Jean-Pierre Colinge, Kluwer Academic Publishers, pp 50 and 51.

Referring to Figure 2a, a donor substrate 30 comprises a wafer of monocrystalline silicon 31 on which an upper layer of relaxed SiGe 322 has been formed via the intermediary of a buffer layer 321.

The layer of relaxed SiGe 322 is advantageously formed by epitaxial growth on the surface of the buffer layer 321.

Its thickness can vary widely depending on circumstances; it is typically in the range 0.5 microns (μm) to 1 μm.

In Figure 2a, reference number 32 designates the assembly constituted by the buffer layer 321 and the layer of relaxed SiGe 322.

A support substrate 40 formed from oxidized silicon is also shown in Figure 2a. It comprises a wafer of silicon 45, a layer of thermal oxide 46, and a free surface 44 (on the side of the layer of oxide 46) onto which the upper layer 322 of the donor substrate 30 is to be bonded.

Referring to Figure 2b, a film of strained monocrystalline silicon 33 which will constitute a bonding layer is grown on the upper layer of relaxed SiGe 321.

The silicon comprised in the film 33 is effectively obliged by the layer of relaxed SiGe to increase its nominal lattice parameter to render it substantially identical to that of its growth substrate, and thus has internal tensile stresses.

The film 33 of strained monocrystalline Si is advantageously formed by epitaxial growth using known techniques such as CVD and MBE (chemical vapor deposition and molecular beam epitaxy respectively).

Epitaxial growth of the monocrystalline strained bonding layer 33 can be carried out:

- in situ, directly by continuing the formation of the subjacent layer of SiGe 322; or
- following a light step of surface finishing the subjacent layer of SiGe, for example by CMP (chemical-mechanical polishing).

The thickness of the Si film 33 is quite low, below a critical thickness, so that there is no relaxation within the thickness of the film 33 of the strain imposed by the layer 322 of relaxed SiGe towards the nominal lattice parameter of silicon and/or a generation of defects in the film 33.

Said critical thickness clearly depends on the concentration of germanium in the layer of SiGe which imposes the strain. Put simply, the higher the concentration, the lower the critical thickness.

The thickness of the Si film is also selected in a manner so that the bonding layer which will be constituted from said film 33 can disappear after bonding, as will be described in more detail below, by diffusion of germanium within its thickness, it being assimilated and homogenized with the layer of SiGe 322.

It should be noted that the strain imposed on the film 33 is a factor that encourages said diffusion of germanium in the bonding layer, for homogenization with the layer of SiGe 322.

Considering a layer of SiGe 322 with a germanium concentration of the order of 20%, the thickness of the film 33 must typically be less than 20 nm to prevent the strain from relaxing.

The strained film 33 is preferably about 5 nm thick to allow its complete disappearance by assimilation with the SiGe layer 322 during diffusion of the germanium contained therein.

Alternatively, it is possible to deposit a layer of polycrystalline or amorphous Si on the SiGe upper layer 322 rather than a film of strained monocrystalline Si.

In this alternative, little or no strain is observed in the Si layer. Thus, it is possible to deposit a layer of polycrystalline or amorphous Si of the desired thickness with no limitations as regards its thickness, in particular when partial oxidation of said Si layer is envisaged prior to bonding.

Referring to Figure 2c, atomic or ionic species are implanted in a manner that is known per se, through the film of monocrystalline Si 33, into the SiGe upper layer 322, to create a zone of weakness (shown as a dotted line) in the thickness of said SiGe upper layer 322.

In a particular implementation of the invention, prior to the implantation step, a step is carried out to deposit a protective layer on the bonding layer.

Said protective layer can protect the surface of the bonding later, in particular from the effects of implantation.

More particularly, deposition of said protective layer is advantageous when the bonding layer does not include an upper layer of oxide (said upper layer of oxide being obtained, for example, by partial oxidation of the bonding layer, as is the case of the alternatives described below).

Clearly, the protective layer is removed prior to bonding the donor structure to the support substrate.

The surface of the Si film 33 and the free surface 44 are prepared, prior to bonding, in a manner that is conventional per se, to reinforce the bonding strength of the donor substrate with the support substrate 40 of oxidized silicon.

One thus carries out a cleaning of the bonding layer (Si film 33) so as to master its bonding, for example by carrying out a hydrophilic treatment, in particular a treatment in a SC1 type solution.

Referring to Figure 2d, the implanted donor structure comprising the cleaned Si film 33 on its top is brought into intimate contact with the free surface 44 of the oxidized support substrate 40. A well mastered Si/oxide bonding is thus achieved.

Different alternatives to this implementation of the invention can be envisaged (cf the variation to the first implementation of the invention mentioned above).

In a first alternative, the strained Si film 33 can be partially oxidized prior to bonding to form a layer of thermal oxide in the superficial region of the film 33.

This layer of oxide is then used as a bonding layer to produce a bond on an oxidized support substrate.

In a second alternative, the strained Si film 33 can also be partially oxidized. The layer of thermal oxide that is formed is then used as a bonding layer to bond directly to a Si support substrate and it then constitutes the buried oxide layer of the final SGOI structure.

It should be noted that these two alternatives can also be implemented when the bonding layer is formed from polycrystalline or amorphous Si.

Returning to the description of the implementation of the invention, following the indirect bonding step, a step of thinning the donor substrate is carried out to remove a portion of the donor substrate and retain only a portion (and in particular a portion of the upper layer 322 of SiGe which will constitute the useful layer of the final structure).

In the context of the SMARTCUT® type transfer method discussed here, said thinning step is a step that is conventional per se for detaching the donor substrate at the zone of weakness formed during the implantation step mentioned above.

Referring to Figure 2e, following said thinning step, a portion of the donor substrate is transferred to the support substrate, retaining only that part of the donor substrate that is the portion of the SiGe upper layer 322 on the side of the Si film 33 with respect to the implantation zone.

An intermediate structure is obtained comprising the oxidized support substrate 40, the Si film 33 and a thin layer 32' formed from SiGe corresponding to said portion derived from the upper layer 322.

It should be mentioned here that the document by T.A. Langdo et al "SiGe-free strained Si in insulator by wafer bonding and layer transfer", Applied Physics Letters, vol 82 number 24, June 16, 2003, discloses bonding of a layer of strained silicon on a layer of thermal oxide in a manner similar to that described here in the context of this example of the invention and illustrated in Figures 2a to 2e.

The aim of the bonding disclosed in the document by T.A. Langdo et al is different, however, from that of the invention in that it relates to the production of a strained silicon on insulator structure (sSOI), the strain in the Si layer being ensured by the subjacent relaxed layer of SiGe.

The above-cited document does not teach the production of a SGOI structure and a fortiori does not propose any solutions for bonding a layer of relaxed SiGe to an oxidized support substrate and does not envisage the diffusion of germanium from the layer of relaxed SiGe into the layer of strained Si.

Further, in that document, the layer of strained silicon that is transferred is deliberately thick so that it can be preserved and constitute the active electrical layer of the final sSOI structure.

Further, and in particular, that thickness is too great when compared with the constraints imposed by the invention for said layer of strained Si to disappear, as will be described in more detail below, by diffusion of germanium into its thickness, assimilating it and homogenizing it with the SiGe layer.

Returning to the description of the implementation of the invention, following the thinning step and referring to Figure 2f, a step is performed consisting in diffusing germanium from said thin layer 32' of SiGe into the bonding layer (in this case the film of strained monocrystalline silicon 33).

And as was seen above, the strain which is imposed on said film 33 by the SiGe layer encourages the diffusion of germanium through the film 33, the

lattice parameters of said film 33 and said SiGe layer being substantially identical.

This diffusion step can thus:

- cause the Si layer 33 to disappear by assimilating it with the SiGe layer 32';
- obtain a SiGe layer 32" with a homogeneous germanium concentration.

It should be noted that the concentration of germanium in the SiGe layer 32" is almost unchanged compared with that previously present in the SiGe layer 32', in particular because of the ratio between the thicknesses of the SiGe layer 32' and the bonding layer (the thicknesses of the layers shown in the Figures are not to scale).

Said diffusion step comprises heat treatment for the structure obtained after bonding and thinning carried out, for example, between 1000°C and 1100°C for about two hours.

It should be noted that said heat treatment can advantageously be carried out during conventional stabilization steps, in particular in the context of SMARTCUT® type transfer methods, to reinforce the interface between the thin layer and the support substrate.

Finally, a SGOI structure composed of a wafer of Si 45, a buried oxide layer 46 and a thin SiGe layer 32" is obtained which benefits from a good bond quality between SiGe layer 32" and oxide layer 46.

Further, it should be noted that the quality of the buried oxide is that of a thermal oxide. Whatever the variation employed, said buried oxide is obtained by thermal oxidation of the Si substrate 45 and/or by partial thermal oxidation of the Si film 33.

As stated before, prior art oxide on SiGe deposition techniques necessitate polishing said deposited oxide layer prior to bonding, which can cause a lack of homogeneity in the thickness.

The invention permits bonding which does not necessitate a prior polishing step of at least one of the surfaces that are brought into contact. Thus, the buried oxide layer possesses good uniformity as regards thickness.

Clearly, it should be understood that this implementation of the invention is not limited to the structure comprising a buffer layer that is presented here, but can also in particular be applied to any structure comprising a SiGe upper layer.

It should also be understood that the material of the bonding layer is not limited to silicon. As already mentioned above regarding the second implementation of the invention, when bonding to an oxidized support substrate, the material of the bonding layer can be SiGe.

More precisely, a SiGe bonding layer is used with a germanium content (typically less than 20%) so that bonding of said SiGe layer to a layer of oxide SiO_2 can be carried out in a satisfactory manner.

More precisely, in order to master the bonding of a SiGe layer, a cleaning of the SiGe layer is performed before bonding. Such a cleaning step helps to reinforce the bonding strength, and the obtained bonding proves of satisfactory quality for the SiGe bonding layers presenting a germanium content typically lower than approximately 20%. Such a cleaning may be a hydrophilic treatment, in particular a RTA type treatment (comprising in sequence a bath in a SC1 solution and a bath in a SC2 solution).

The use of such a SiGe layer with a low germanium content thus allows a layer of SiGe having a germanium content that is too high to be able to carry out direct bonding of said SiGe layer to an oxidized support substrate to be bonded.

It should be noted that when a $Si_{1-x}Ge_x$ bonding layer with a low concentration x of Ge is used for indirect bonding of an upper layer of $Si_{1-y}Ge_y$ with a concentration y of germanium that is higher ($y > x$), said $Si_{1-x}Ge_x$ bonding layer is strained by said $Si_{1-y}Ge_y$ upper layer.

In a manner that is similar to that described above regarding a bonding layer constituted from a strained monocrystalline Si film, the strain imposed on the $Si_{1-x}Ge_x$ bonding layer is a factor that encourages the diffusion of germanium through said bonding layer, for its homogenization with the $Si_{1-y}Ge_y$ upper layer.

The thickness of the $Si_{1-x}Ge_x$ bonding layer is selected so that there is no relaxation of the strain throughout its thickness and so that said bonding layer can disappear after bonding by diffusion of germanium through its thickness.

It should also be noted that the steps for implanting and detaching at a zone of weakness described above are only mentioned as examples of steps that can bring about thinning, on the donor substrate side, of the structure obtained after bonding.

Other examples of thinning techniques are mentioned below. It should be noted that said examples in no case constitute a limitation, and the

invention encompasses any type of technique that can thin the donor substrate in accordance with the method of the invention.

One technique can, for example, consist in removing material by supplying energy to "cut" the donor substrate at a zone which has been weakened by creating at least one porous layer.

Other techniques consist, for example, in mechanical or chemical-mechanical attack by lapping and/or chemical-mechanical polishing, CMP.

Dry etching techniques such as plasma or spray etching can also be mentioned.

Finally, selective chemical etching techniques can be carried out, in particular when the structure to be etched comprises etch-stop layers.

This is particularly the case with a donor substrate comprising a Si etch-stop layer subjacent to a SiGe upper layer in which said Si etch-stop layer can be used to thin said donor substrate, following bonding by selective etching.

Finally, the invention does not only relate to the indirect bonding of a SiGe layer, but also relates to indirect bonding of any layer of semiconductive material that can be transferred to a support substrate via the intermediary of a bonding layer using the method of the invention.

CLAIMS

1. A method of producing a structure comprising a thin layer (2") of semi-conductive material on a support substrate (20), said thin layer being obtained from a donor substrate (10) comprising an upper layer (2) of semiconductor material, the method being characterized in that it comprises steps of:

- forming on said upper layer (2) a bonding layer (3) of a material that accepts diffusion of an element of the material of the upper layer (2);
- cleaning said bonding layer (3) for mastering its bonding adhesion;
- bonding the donor substrate (10), from the side of the bonding layer (3) previously formed on the upper layer (2) and cleaned, to the support substrate (20); and
- diffusing said element from the upper layer into the bonding layer to homogenize the concentration of said element in the bonding layer and said upper layer, to constitute said thin layer (2") of the structure with said bonding layer and said upper layer.

2. A method according to claim 1, characterized in that, during the step of diffusing said element from the upper layer into the bonding layer, said bonding layer (3) disappears by blending into said upper layer to form said thin layer (2") of the structure.

3. A method according to claim 2, characterized in that it further comprises, following bonding and prior to diffusion, a thinning step aimed at removing a portion of the donor substrate (10) to retain only a portion of the upper layer, to obtain an intermediate structure comprising the support substrate (20), the bonding layer (3) and a thin layer (2') formed by the remainder of the upper layer remaining integral with the bonding layer.

4. A method according to the preceding claim, characterized in that thinning is carried out by detachment from the donor substrate (10) at a zone of weakness formed prior to bonding in the thickness of said upper layer (2).

5. A method according to the preceding claim, characterized in that the zone of weakness is formed by implanting species into the upper layer (2).

6. A method according to claim 5, characterized in that it comprises, prior to implantation, a step aimed at depositing a protective layer on said bonding layer, said protective layer being removed before the bonding step.

7. A method according to any one of claims 3 to 6, characterized in that the thinning step comprises at least one etching step.

8. A method according to any one of claims 3 to 7, characterized in that the diffusion step is carried out by applying a heat treatment to the intermediate structure obtained after thinning.

9. A method according to claim 8, characterized in that the diffusion step is carried out during a heat treatment for stabilizing the bonding interface of the structure obtained after thinning.

10. A method according to claim 8 or claim 9, characterized in that said heat treatment is carried out between 1000°C and 1100°C for about two hours.

11. A method according to any preceding claim, in which said upper layer (322) is formed from silicon-germanium SiGe, characterized in that the diffusion step consists in diffusing the element Ge from said upper layer (322) into the bonding layer (33).

12. A method according to claim 11, characterized in that the step of forming the bonding layer comprises depositing a film of strained silicon Si on said SiGe upper layer (322).

13. A method according to claim 12, characterized in that the bonding layer is formed by epitaxial growth of a film (33) of strained monocrystalline silicon on said SiGe upper layer (322).

14. A method according to claim 13, characterized in that said the thickness of said strained epitaxially grown Si film (33) is about 5 nm.

15. A method according to claim 13 or claim 14, characterized in that bonding is carried out on an oxidized support substrate (40) to produce a good quality Si/oxide bond.

16. A method according to claim 13 or claim 14, characterized in that it further comprises, following formation of said strained Si film and prior to cleaning, a step of partial thermal oxidation of said strained Si film to form a layer of a thermal oxide on the surface of said strained Si film.

17. A method according to claim 16, characterized in that bonding is carried out directly on an oxidized support substrate to produce a good quality oxide/oxide bond.

18. A method according to claim 16, characterized in that bonding is carried out directly onto a silicon support substrate to produce a good quality oxide/Si bond.

19. A method according to any one of claims 12 to 18, characterized in that the cleaning of the bonding layer is performed with a SC1 type solution.

20. A method according to claim 11, characterized in that the step of forming the bonding layer comprises depositing, on said SiGe upper layer, a film of SiGe with a germanium concentration so that bonding of said deposited SiGe film to a layer of oxide is mastered.

21. A method according to claim 20, characterized in that the concentration of germanium in said deposited SiGe film is less than 20%.

22. A method according to claim 20 or claim 21, characterized in that bonding is carried out directly to an oxidized support substrate to achieve a good quality SiGe/oxide bond.

23. A method according to claim 15 or claim 22, characterized in that during the diffusion step, the element Ge diffuses into the bonding layer so that a layer with a homogeneous concentration of germanium is obtained by assimilation of said bonding layer with said SiGe upper layer.

24. A method according to claim 17 or claim 18, characterized in that during the diffusion step, the element germanium Ge diffuses into the non-oxidized portion of the strained silicon film partially oxidized prior to bonding, so that a layer with a homogeneous concentration of germanium is obtained by assimilation of said non-oxidized portion of the partially oxidized strained silicon film with said SiGe upper layer.

25. A method according to any one of the preceding claims, characterized in that the cleaning of the SiGe bonding layer is performed according to a RCA type treatment.

26. A method according to any one of the preceding claims, characterized in that the cleaning step also comprises the cleaning of the face (4) of the support substrate which is to be bonded to the bonding layer (3).

27. A method of bonding together a first and a second wafers of semi-conductive material, the first wafer comprising an upper layer and the second wafer comprising a free face, characterized in that it comprises the steps of:

- forming, on the upper layer of the first wafer, a bonding layer of a material that accepts diffusion of an element of the material of said upper layer;
- cleaning said bonding layer (3) for mastering its bonding adhesion;
- bonding the donor substrate (10), from the side of the bonding layer (3) previously formed on the upper layer (2) and cleaned, to the support substrate (20); and
- diffusing said element of the upper layer into the bonding layer to homogenize the concentration of said element in the bonding layer and said upper layer, said bonding layer disappearing by blending with said upper layer so that said wafers are bonded together, the upper layer of the first wafer being connected to the free face of the second wafer.