"RECYCLING BY MECHANICAL MEANS OF A WAFER COMPRISING A TAKING-OFF STRUCTURE AFTER TAKING-OFF A THIN LAYER THEREOF"

FIELD OF THE INVENTION

The present invention relates to the recycling of a donor wafer after having taken off a layer of semiconductor material, the recycling comprising a removal of substance involving a portion of the donor wafer on the side where the taking-off took place.

BACKGROUND OF THE INVENTION

Before taking-off, such a donor wafer comprises a substrate and the layer to be taken off epitaxially deposited on the substrate.

After taking-off, the taken off layer is integrated with a structure in which components will be formed, particularly in the fields of microelectronics, optics, or optoelectronics, for the most part.

The layer to be taken off must therefore attain a high level of quality determined according to one or more specific criteria.

The quality of the layer to be taken off largely depends on the growth support, that is, on the quality of the substrate on which it is epitaxially deposited.

The formation of such a high quality substrate is often complex and requires particular attention, involving technical difficulty and a raised economic cost.

This latter point is further confirmed on considering a layer to be taken off consisting of composite semiconductor material such as an alloy, the epitaxy substrate also having to exhibit a structure which is often difficult and costly to implement.

Thus a substrate comprising a buffer layer specifically exhibits such difficulties of implementation.

By "buffer layer" is generally understood a transition layer between a first crystalline structure such as a support substrate and a second crystalline structure having as a first function a modification of the properties of the

material, such as structural, stoichiometric properties or a surface atomic recombination.

In a specific case of a buffer layer, the latter can permit obtaining a second crystalline structure, whose lattice parameter differs substantially from that of the support substrate.

A first technique of forming a buffer layer consists in effecting the growth of successive layers so as to form a structure having a composition varying gradually in thickness, the gradual variation of components of the buffer layer then being directly associated with a gradual variation of its lattice parameter.

A layer, or superposed layers, formed on the buffer layer can be taken off from the donor wafer, to be transferred to a receiving substrate so as to form a well-defined structure.

One of the main applications of a transfer of thin layers formed on a buffer layer concerns the formation of layers of elastically stressed silicon, and especially, in the case where the silicon is stressed in tension, because certain of its properties, such as electron mobility in the material, are then distinctly improved.

Other materials, such as for example SiGe, can also be the subject of a substantially analogous taking-off.

A transfer of such layers onto a receiving substrate, specifically by a method termed Smart-Cut® known to those skilled in the art, then permits structures to be formed such as SeOI (Semiconductor On Insulator) structures.

For example, after a taking-off of an elastically relaxed layer of SiGe, the structure obtained, including the taken-off layer, can then serve as a growth support for silicon which will be placed under tension by the layer of relaxed SiGe.

As an illustration, an example of such a method is described in the IBM document of L.J. Huang et al., ("SiGe-On-Insulator prepared by wafer bonding and layer transfer for high-performance field-effect transistors",

Applied Physics Letters, 26/02/2001, Vol. 78, No. 9) in which a process is given for forming an Si/SGOI structure.

Other applications of growth on a buffer layer are possible, particularly with Group III-V semiconductors.

Transistors are thus commonly formed in technologies based on GaAs or based on InP.

In terms of electronic performance, InP has an appreciable advantage over GaAs.

For the main reasons of cost and feasibility, the chosen technique consists of transferring to a receiving substrate a taken-off layer of InP obtained by growth on a buffer layer on a support substrate of GaAs.

Certain taking-off methods, such as a method of the "etch-back" type, then entail a destruction of the remaining portion of the support substrate and of the buffer layer during taking-off.

In certain other methods of taking-off, the support substrate is recycled but the buffer layer is lost.

The technique of formation of a buffer layer is complex.

Moreover, to minimize its density of crystallographic defects, the thickness of a buffer layer is generally considerable, typically between one and several micrometers.

The production of such a buffer layer thus leads to an often long, difficult and costly implementation.

A second technique of production of a buffer layer is disclosed in particular in the document WO 00/15885, and has as its main object to elastically relax a layer of Ge stressed by means of a Ge buffer layer.

This technique is based on specific epitaxy conditions, specifically associating the parameters of temperature, time, and chemical composition.

With respect to the first technique, it has the main advantage of being simpler, shorter, and less costly to perform.

The buffer layer finally obtained is moreover not as thick as a buffer layer formed according to the first technique.

A third technique of formation of a buffer layer is disclosed by B. Höllander et al., particularly 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).

It consists of relaxing elastic stresses present in the layer to be taken off by means of a deep hydrogen or helium implantation.

Thus from this point of view, this third technique can give a result close to a buffer layer produced according to one of the two previous techniques with substantially less demands of implementation.

The method describes specifically a relaxation of a SiGe layer stressed in compression, this layer being formed on an Si substrate.

The technique used comprises implantation of hydrogen or helium ions through the surface of the stressed layer in the Si substrate to a given depth, generating perturbations in the thickness of Si above the implanted zone (this thickness then forms a buffer layer) and causing, under heat treatment, a certain relaxation of the SiGe layer.

This technique seems to be less long, easier to practise, and less costly than the first technique of forming a buffer layer.

An advantage of using this technique would be to later integrate this relaxed or pseudo-relaxed layer into a structure for the fabrication of components, particularly for electronics or opto-electronics.

However, in a manner similar to the first technique for forming a buffer layer, a buffer layer made according to one of the last two techniques is removed during the known techniques of recycling of the donor wafer after taking-off.

Technical difficulties of implementation remain in carrying it out.

SUMMARY OF THE INVENTION

Embodiments of the present invention seek to improve the situation. According to a first aspect of the present invention, there is provided a method of recycling a donor wafer after having taken off a useful layer comprising a material chosen from semiconductor materials, the donor wafer comprising successively a substrate and a taking-

off structure, the taking-off structure before taking-off comprising the useful layer to take off, the method comprising removal of substance on the side where the taking-off took place, characterized in that the removal of substance comprises employing mechanical means so that, after removal of substance, at least a part of the taking-off structure remains, this at least part of the taking-off structure including comprising at least one other useful layer that can be taken off after recycling, without a supplementary step of reforming a useful layer.

According to a second aspect of the present invention, there is provided a method of taking-off a useful layer from a donor wafer by transferring it to a receiving substrate, characterized in that it comprises:

(a) bonding the donor wafer to the receiving substrate on the side of the useful layer to be taken off;

(b) detaching the useful layer comprised in the taking-off structure of the donor wafer;

(c) recycling the donor wafer according to the said recycling process.

According to embodiments of the present invention, there is provided a method of cyclic taking-off of a useful layer from a donor wafer, characterized in that it comprises a succession of steps of taking-off of a useful layer, each of these steps being complying with the method of recycling according to embodiments of the invention.

According to alternate embodiments of the present invention, there is provided an application of a method of cyclic taking-off or of a method of taking-off according to embodiments of the invention, to the formation of a structure comprising the receiving substrate and the useful layer, the useful layer comprising at least one of the following materials:
SiGe, Si, an alloy belonging to Group III-V whose composition is respectively chosen from among the possible combinations (Al, Ga, In) - (N, P, As).

According to further embodiments of the present invention, there is provided a donor wafer having provided a useful layer by taking-off, and capable of being recycled by a method according to embodiments of the invention, characterized in that it successively comprises a substrate and a remaining part of the taking-

off structure having provided the useful layer, characterized in that, after taking-off, the remaining part of the taking-off structure is still sufficient thick for containing at least one other useful layer to be taken-off.

BRIEF DESCRIPTION OF THE INVENTION

Other aspects, objects and advantages of the present invention will better become apparent on reading the following detailed description of implementation of preferred methods thereof, given as a non-limiting example and made with reference to the accompanying drawings, in which:

Figure 1 shows the different steps of a method according to the invention, comprising in succession a taking-off of a thin layer from a donor wafer and a recycling of the donor wafer after taking-off.

DETAILED DESCRIPTION OF THE INVENTION

The principal purpose of the present invention consists of recycling a wafer comprising a taking-off structure, after at least one useful layer (that is, the portion of the donor layer being taken off) has been taken off in order to integrate the latter into a semiconductor structure, the recycling being implemented such that the remaining portion of the taking-off structure can again provide a useful layer in a later taking-off after recycling, without the use of a step of reforming a useful layer, such as a step of crystalline growth by epitaxy.

Recycling should specifically comprise a suitable treatment which does not cause deterioration of a portion of the taking-off structure in which the useful layer is included, so that after recycling it remains possible to take off the useful layer.

In a specific configuration, there could be several useful layers which can be taken off, and it could thus be possible to have a succession of several successive takings-off, between which a recycling method according to the present invention will advantageously be used.

Referring to Figures 1a and 1b, the donor wafer 10 is constituted by a substrate and a taking-off structure l.

In a first configuration of the substrate 1, the latter is constituted by a single crystalline material having the first lattice parameter.

In a second configuration of the substrate 1, the latter is a "pseudo-substrate" constituted by a support substrate and a buffer structure interfaced with the taking-off structure I.

Any structure behaving as a buffer layer is termed a "buffer structure".

It advantageously has at the surface a crystallographic structure which is substantially relaxed and/or is without an appreciable number of structural defects.

Advantageously, the buffer layer has at least one of the two following functions:

- reduction of the density of defects in the upper layer;
- adaptation of a lattice parameter between two crystallographic structures having different lattice parameters.

To perform the second function, the buffer layer has, in the neighbourhood of one of its faces, a first lattice parameter substantially identical to that of the support substrate and in the neighbourhood of its other face a second lattice parameter substantially identical to that of the layer of the taking-off structure I directly overlying the buffer structure.

In a first configuration of the buffer layer, the latter is constituted by a single buffer layer.

The buffer layer, situated on the support substrate, permits the presentation at its surface of a lattice parameter substantially different from the lattice parameter of the support substrate, and thus permits having on the same donor wafer 10, a layer having a lattice parameter different from that of the support substrate.

In certain applications, the buffer layer can furthermore permit the overlying layer to avoid containing a high density of defects and/or undergoing substantial stresses.

The buffer layer can furthermore permit the overlying layer, in certain applications, to have a good surface state.

According to a first technique of forming a buffer structure, a buffer layer is formed so as to have a lattice parameter undergoing an overall

progressive modification over a substantial thickness for bringing about the transition between the two lattice parameters.

Such a layer is generally termed a metamorphic layer.

This modification of the lattice parameter can be effected in a continuous manner in the thickness of the buffer layer.

Or it can be effected by "steps", each step being a thin layer with a substantially constant lattice parameter, different from that of the underlying step, so as to modify the lattice parameter in a discrete fashion step by step.

It can also have a more complex form such as a variation of composition at a variable rate, a reversal of sign of the rate, or discontinuous jumps of composition.

The progression of the lattice parameter in the buffer layer is advantageously found by substantially progressively augmenting the concentration there, starting from the support substrate, of at least one atomic element which is not comprised in the support substrate.

Thus, for example, a buffer layer formed on a support substrate of unitary material could be of a material which is binary, tertiary, quaternary or more. The buffer layer is advantageously formed by growth on the support substrate, for example, by epitaxy using the known techniques such as CVD and MBE (respective abbreviations of "Chemical Vapor Deposition" and "Molecular Beam Epitaxy").

Generally, the buffer layer can be formed by any other known method, in order to obtain, for example, a buffer layer constituted by an alloy of different atomic elements.

A light step of surface finishing the support substrate underlying the buffer layer, for example by CMP polishing, can if necessary precede the forming of the buffer layer.

In another configuration, the buffer layer formed by the first technique is comprised in a buffer structure which is constituted by a buffer layer (substantially identical to that of the first configuration) and an additional layer.

The additional layer can be between the support substrate and the buffer layer, or on the buffer layer.

In a first specific case, this additional layer can constitute a second buffer layer, such as a buffer layer permitting defects to be confined, thus improving the crystalline quality of the taking-off structure I formed on the buffer structure.

This additional layer is of semiconductor material, preferably having a constant material composition.

The chosen composition and thickness of such an additional layer to be formed are then particularly important criteria for attaining this property.

Thus, for example, the structural defects in an epitaxial layer usually decrease gradually in the thickness of this layer.

In a second specific case, the additional layer is situated on the buffer layer and has a constant composition of relaxed material.

It can thus fix the second lattice parameter.

The additional layer can also have several functions, such as functions chosen from among these two last specific cases.

In an advantageous configuration, the additional layer is situated on the buffer layer and has a lattice parameter substantially different from the lattice parameter of the support substrate.

In a specific case of this advantageous configuration, the additional layer is of material relaxed by the buffer layer.

The additional layer is advantageously formed by growth on the buffer layer, for example by epitaxy by CVD or MBE.

In a first embodiment, the growth of the additional layer is performed in situ, directly following the formation of the underlying buffer layer, the latter also being advantageously formed by layer growth in this case.

In a second embodiment, the growth of the additional layer is effected after a step of light surface finishing of the underlying buffer layer, for example by CMP polishing, thermal treatment, or other smoothing technique.

A second technique of forming a buffer structure is based on a technique of depositing a layer superficially onto a support substrate, this superficial layer having a nominal lattice parameter substantially different

from the lattice parameter of the neighbouring material of the support substrate surface.

This deposition of the superficial layer is performed in such a manner that the deposited layer is practically free from plastic defects such as dislocations.

This superficial layer is formed so as to have when finished:

- a first portion in contact with the support substrate, which confines plastic defects such as dislocations, and
- a second portion, relaxed or pseudo-relaxed by the first portion, and having no or few plastic defects.

The first portion of the deposited superficial layer then plays the part of a buffer layer, because:

- it confines the plastic defects in order to preserve the second portion of the superficial layer; and
- it adapts the lattice parameter of the superficial layer to that of the substrate.

By "confinement" is meant that the great majority of the plastic defects are found in the first portion. The second portion of the superficial layer is not absolutely free from defects, but their concentration is compatible with microelectronic applications.

The deposition technique used for forming such a buffer layer advantageously includes variations in the temperature and chemical composition times of the deposition.

It is thus possible to succeed in forming a buffer layer having a chemical composition substantially constant over the thickness, contrary to a buffer layer formed according to the first technique.

One or more layers can, however, be intercalated between the buffer layer and the second portion of the superficial layer.

The buffer layer may furthermore have a thickness less than the smallest thicknesses of buffer layers formed by the first technique.

The document WO 00/15885 teaches an example of formation of such a buffer layer according to this last technique, performing a deposition of SiGe or of Ge on a monocrystalline Si support substrate.

Such a method of deposition can also be effected, for example, according to a mode in which a deposition of monocrystalline Ge is performed on a monocrystalline Si support substrate, by using the following steps:

- stabilization in temperature of a monocrystalline silicon *support substrate* at a first predetermined stabilized temperature of 400°C to 500°C, preferably 430°C to 460°C;
- chemical vapour phase deposition (CVD) of Ge at the said first determined temperature until obtaining a *base layer* of Ge on the support substrate, of a predetermined thickness less than a desired final thickness;
- increase of the Ge chemical vapour phase deposition temperature from the predetermined first temperature up to a predetermined second temperature ranging from 750°C to 850°C, preferably 800°C to 850°C; and
- proceeding with Ge chemical vapour phase deposition at the said predetermined second temperature until the desired final thickness is obtained for the superficial layer of monocrystalline Ge.

The buffer layer is the portion of the deposited layer which is interfaced with the support substrate and which extends over a thickness for which the rate of crystallographic defects is greater than a limit value.

The thickness of this buffer layer can specifically be of the order of 0.5 to 1 micron, which is less than the thickness of a buffer layer formed according to the first technique.

The other portion of the layer is at least a portion of the taking-off structure I.

Such a method of deposition can equally be effected according to alternatives – for example, those disclosed by the document WO 00/15885.

In this manner the substrate 1 of the donor wafer 10 has been formed, the substrate 1 comprising the said support substrate and the said buffer layer.

A third technique of forming a buffer structure is used on a structure comprising the substrate 1 and a layer which has been deposited on the substrate 1.

The material chosen to constitute this layer is a material having a nominal lattice parameter which is substantially different from the lattice parameter of the surface of the substrate 1, so as to have to be elastically stressed in compression or in tension by the substrate 1.

The stressed layer has a general structure of stressed material, but can also contain one or more thicknesses of relaxed or pseudo-relaxed material which have a cumulated thickness very much less than that of the stressed layer, so that the latter retains an overall stressed state.

In all cases, the stressed layer is advantageously formed on the substrate 1 by crystalline growth, such as epitaxy using known techniques, for example, CVD and MBE.

To obtain such a stressed layer without too many crystallographic defects, such as for example point defects or extended defects such as dislocations, it is advantageous to choose the crystalline material constituting the substrate 1 and the stressed layer (in the neighbourhood of its interface with the substrate 1) so that they exhibit a sufficiently low difference between their respective first and second nominal lattice parameters.

For example, this difference in lattice parameter is typically comprised between about 0.5% and about 1.5%, but can also have larger values.

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

On the other hand, it is preferable for the stressed layer to have a substantially constant thickness, so that it has substantially constant intrinsic properties and/or to facilitate future bonding to the receiving substrate (as shown in Figure 1b).

To avoid a relaxation of the stressed layer or an appearance of plastic type internal stresses, the thickness of the said layer should furthermore remain less than a *critical thickness of elastic stress*.

This critical thickness of elastic stress principally depends on the principal material chosen to constitute the stressed layer and the said difference in lattice parameter from the substrate 1.

Those skilled in the art will refer to the state of the art to know the critical thickness of elastic stress value which is used for the stressed layer formed on the material used for the substrate 1.

Once formed, the stressed layer thus has a lattice parameter substantially close to that of its growth substrate 1, and then has internal elastic stresses in compression or in tension.

Once the structure is formed, the third technique of forming a buffer structure comprises a first step of formation in the substrate 1 of a perturbation zone at a given depth.

A perturbation zone is defined as a zone having internal stresses able to form structural perturbations in the surrounding portions.

This perturbation zone is advantageously formed on substantially all the surface of the substrate 1`and parallel to the surface of the substance 1.

A method of formation of such an embrittlement zone comprises an implantation of atomic species in the substrate 1 at the said given depth, with a given implantation energy and a given dose of atomic species.

In a particular embodiment of the implantation, the atomic species implanted comprise hydrogen and/or helium.

Such a perturbation zone formed by implantation then comprises internal stresses, or even crystallographic defects, brought about by the implanted atomic species in the crystalline network adjacent to the perturbation zone.

These internal stresses are then able to create crystallographic perturbations in the overlying zone.

For this purpose, the buffer zone is formed according to this third technique during the performance of a second step by an adapted supply of energy adjusted to suitable parameters for:

- aiding the appearance of perturbations in the region overlying the perturbation zone;
- increasing the extent of these perturbations in this overlying region; and
- causing an at least relative elastic relaxation of the stressed layer following the appearance of perturbations.

The principal purpose of such a supply of energy is thus to cause an at least relative relaxation of the elastic stresses of the stressed layer in order to form a *relaxed stressed layer*.

The intermediate region comprised in the substrate 1 between the perturbation zone and the stressed layer:

- confines defects of the dislocation type;
- adapts the lattice parameter of the substrate 1 to the nominal lattice parameter of the stressed layer;

This intermediate region can thus be considered here as a *buffer layer*.

A heat treatment is advantageously performed in order to generate, if its parameters are suitable, the said energy supply sufficient to cause these structural modifications.

This said thermal treatment is advantageously performed at a temperature or temperatures substantially lower than a critical temperature beyond which a significant number of implanted atomic species will be degassed.

Starting from internal stresses in the perturbation zone, local crystallographic perturbations are thus created.

Particularly because of minimizing the elastic energy in the region of the stressed layer, these perturbations principally appear in the buffer layer and increase in amplitude under the effect of the thermal treatment.

When these perturbations have become sufficiently great, they act on the stressed layer, relaxing at least relatively the elastic stresses there, these

relaxed stresses being principally lattice misfit stresses between the respective nominal lattice parameters of the material of the stressed layer and that of the substrate 1.

However, the relaxation of the stressed layer may also be accompanied by the appearance of inelastic type crystalline defects, such as traversing dislocations, in the thickness of the said layer.

Suitable treatments, such as a heat treatment, may then be performed to reduce the number of these defects.

A suitable treatment can be made use of, for example, which permits increasing the density of dislocations until it is comprised between two limit values, the limit values defining an interval of density of dislocations within which at least a portion of the dislocations is annihilated.

In any case, there is finally obtained a relaxed or pseudo-relaxed layer whose nominal lattice parameter is substantially different from the nominal lattice parameter of the growth substrate 1 and which has a low amount of dislocations prejudicial to the formation of microelectronic components in the relaxed stressed layer.

This relaxed or pseudo-relaxed layer can constitute at least a portion of the taking-off structure I.

For more details, reference may be made to B. Höllander et al., specifically in the document entitled "Strain relaxation of pseudomorphic $Si_{1-x}Ge_x$ / Si(100) heterostructures after hydrogen or helium implantation for virtual substrate fabrication" (in Nuclear and Instruments and Methods in Physics Research B 175-177 (2001) 357-367).

The buffer layer thus produced by this third technique of forming the buffer structure is then comprised in the substrate 1 as defined before the implementation of this third technique of forming a buffer layer.

A fourth technique of forming a buffer structure is based on a support substrate of the buffer structure to be formed, the surface of which is in relief; and a deposition of elements constituting the buffer structure on the support substrate.

Given the non-flatness of the support substrate surface, the deposition of the elements constituting the buffer structure is performed in an anisotropic fashion with selective growth effects and local coalescences which confer specific properties on the formed buffer structure.

This fourth mode of forming a buffer structure puts specific techniques and parameters into effect such that the obtained properties of the buffer layer correspond to properties of confinement of crystallographic defects, in order for the taking-off structure I which will be formed on the buffer structure to have a high quality intrinsic structure.

The choice of the topography of the support substrate is one of the essential data for obtaining such a result.

In particular, a topography will preferably be chosen with periodically repeated patterns over the whole surface of the support substrate, in order to homogenize its effect on the whole surface of the wafer.

For example, the support substrate may exhibit bands, spaced apart by a given distance.

For such a topography in bands, and under certain deposition conditions, it is possible to succeed in concentrating the dislocations of the epitaxial layers in the neighbourhood of the bands, and particularly the corners of the bands.

The thickness of the layer in which the major portion of the dislocations is concentrated then constitutes the *buffer layer*.

For this specific support substrate surface topography in periodically spaced bands over the whole surface of the support substrate, the bands are advantageously constituted by an insulating material formed on a substrate and thus constituting a mask for the materials which will later be deposited.

Moreover, there may be intercalated between a solid substrate and the relief structure an intermediate layer of crystalline material serving as growth substrate for the buffer layer, the insulating relief structure then being sufficiently fine to not perturb the resumption of growth of the buffer structure on the growth substrate underlying it.

This technique is also termed epitaxial lateral overgrowth, or "ELOG", and is principally applied to nitride film deposition by MOCVD (Metal Organic Chemical Vapor Deposition) epitaxy.

There could be used as a basis, for example, the Bulletin of the "Materials Research Community" of May 1998, Volume 23, No. 5, in the article by Shuji Nakamura entitled "InGaN/GaN/AlGaN-Based Laser Diodes with an Estimated Lifetime of Longer than 10,000 hours" in which growth of GaN on a banded structure of SiO_2 is specifically described.

A structure of GaN formed according to this fourth technique of buffer structure formation by ELOG will be described later in this document, in Example 9.

Whatever the structural configuration of the substrate 1 (which does or does not include a buffer structure), the said structure is constituted by a crystalline material, exhibiting few or no crystallographic defects, in the region of the interface with the taking-off structure I.

At least one portion of the different layers constituting the taking-off structure I is advantageously formed by growth on the substrate 1, for example by epitaxy by CVD or MBE.

In a first embodiment, growth of at least a portion of these layers is performed in situ, directly in continuation of the formation of the layers which respectively underlie them, these layers also being advantageously formed by layer growth in this case.

In a second embodiment, growth of at least a portion of these layers is performed after light steps of surface finishing of the layers which respectively underlie them, for example by CMP polishing, heat treatment, or other smoothing treatment.

A taking-off structure I is finally obtained, comprising layers of crystalline materials.

The taking-off structure I comprises, before recycling, a thickness equivalent to or greater than at least two useful layers.

However, the taking-off structure I very advantageously has a thickness greater than two useful layers, in order to free itself from the

thicknesses of material removed during treatment(s) performed during recycling to clear up defects created most of the time during taking-off of the useful layer.

It is indeed usual to find roughness, inhomogeneities of thickness, structural defects and/or defects of other types, at the surface of a donor wafer 10 after taking-off, like those encountered in the post-taking-off structure I' (see Figure 1c).

For example, projecting and/or rough portions can appear after taking-off in the region of the taking-off surface of the remaining donor wafer 10.

These superficial relief portions which appear on the surface of the taking-off structure I principally depend on the manner of taking-off and on the taking-off technique used.

- Thus, for example, a kind of taking-off currently used in industry consists of taking off the useful layer, not over the whole surface of the donor wafer 10, but only from a portion of the latter (which is generally a substantially centred portion), leaving projecting portions on the surface of the donor wafer 10. These projecting portions are generally monolithic and situated peripherally on the surface of the donor wafer 10, the set of projecting portions then being termed in industry "taking-off crown".

- Thus, for example, known taking-off techniques, such as for example those which will be studied hereinafter, such as the Smart-Cut® technique already mentioned, sometimes cause surface roughnesses.

The taking-off structure I before taking-off thus should have a thickness of at least two useful layers to be taken off and a thickness equal to or greater than a thickness margin corresponding to the minimum material to be removed during recycling(s).

This thickness margin is thus typically of the order of a micron in the case of recycling after a Smart-Cut® type taking-off (discussed hereinafter).

However, this thickness margin could be reduced by using efficient recycling techniques such as selective chemical etching.

A principal treatment implemented during recycling according to the invention is a treatment of removal of substance adapted to preserve a

portion of the taking-off structure I including at least another useful layer which can be taken off after recycling.

This/these removal(s) of material is/are performed on the donor wafer 10, that is, in the region of the free surface of the taking-off structure I which remains after taking-off.

In the context of the invention, any removal of substance includes the use of mechanical means for removing material (such as polishing or lapping).

This treatment can be performed on the surface and is used for removing a superficial portion of the taking-off structure I from which the useful layer has been taken off, and in particular permits removal of a superficial thickness containing surface defects which have appeared during taking-off, such as crystallographic perturbations of the dislocations or point defects type.

This treatment can advantageously be performed in depth in the specific case where the taking-off technique used generated defects present deeper in the thickness of the taking-off structure I.

A technique of removal of substance by mechanical means of the polishing type currently used consists of disposing a donor wafer 10 between a polishing head and a polishing plate which can rotate around a drive shaft.

The respective principal surfaces of the polishing head and the polishing plate are substantially parallel.

A force applied to the polishing head applies the donor wafer 10 against the upper face of the plate.

The rotating movement of the donor wafer 10 with respect to the plate then causes rubbing on one face of the donor wafer 10, and thus polishes this face.

In a preferred mode, the polishing head, accompanied by the donor wafer 10, is displaced on the upper surface of the polishing plate along a given path in order to best homogenize the polishing. This movement can, for example, be a reciprocating translational movement along a given axis, or a helical movement.

The polishing plate is advantageously covered with a textured or woven material.

A polishing solution permitting lubrication of the rubbing actions of the plate on the donor wafer may advantageously be injected.

A post-polishing cleaning of the surface of the wafer, generally with deionized water which is injected, can follow the polishing.

A post-polishing rinsing can be performed between polishing and cleaning, generally with a solution including a suitable surfactant, which is injected. The primary function of the surfactant is to maximally disperse in the rinsing solution the residual particles which can continue to erode the surface of the slice, and thus to reduce their deposition on the surface and permit their evacuation.

One or more of these solutions are advantageously injected so as to wet the fabric covering the plate which thus best distributes the solution over the whole surface of the donor wafer 10.

In a first embodiment of the plates, the said functions of polishing, rinsing, and cleaning plates are performed by only a single plate.

But to improve the productivity of the whole method, devices with several plates are preferred:

In a second embodiment of the plates, the polishing function is fulfilled by a polishing plate, and the functions of rinsing and cleaning are fulfilled by a single plate termed rinsing/cleaning plate. This embodiment, which decouples polishing from the rinsing/cleaning, improves the quality of rinsing by using for rinsing a plate which is "virgin" of all particulate residues which could remain stuck to a plate.

In a third embodiment of plates, the polishing plate, the rinsing plate, and the cleaning plate are separate plates. This embodiment decouples, with respect to the second embodiment, the rinsing from the cleaning, and thus improves the final cleanliness of the surface of the slice, using for cleaning a plate virgin of all particulate residues which could remain stuck to a rinsing plate.

In addition to polishing, abrasive particles such as particles of silica can be introduced to improve the attack of the material.

In addition to polishing, chemical agents can be introduced in order to accompany the mechanical attack effected by the polishing plate with a chemical attack.

In an advantageous embodiment of removal of substance from the donor wafer 10, a mechano-chemical planarization, again termed CMP, is used, the principle of which is to bring together the polishing surface of the polishing plate and a polishing fluid which includes abrasive particles and a chemical attack agent.

In addition to mechanical polishing, the polishing fluid then conjointly effects chemical etching by means of the attack agent, and a mechanical etching by means of abrasive particles, of the donor wafer 10 surface to be polished.

The removal of substance may again be followed by rinsing and/or cleaning of the polished surface of the donor wafer 10.

It is to be noted that the rinsing can in some cases not only act on a more rapid removal of residual and abrasive polishing particles, but also on the chemical polishing action.

Indeed, if the chemical attack agent used during polishing has a basic pH, by adding a surfactant, generally acid, to the polishing solution, rapid stopping of the chemical action of the polishing solution is favoured.

For certain semiconductor materials such as silicon, the chemical action is preponderant over the mechanical action (the abrasive particles used during the surface polishing of such semiconductor materials being of small size).

Such a rinsing with an acid surfactant, especially for the materials mentioned in the last paragraph, thus permits the polishing action to be significantly stopped and its effect on the slice to be controlled. In this way, the post-polishing thickness is thus ensured and reproducible.

Control of the stopping of polishing, and thus more precise control of the thickness removed, can be obtained in this manner.

Furthermore, a progressive injection of the rinsing solution will be preferred: too rapid an injection would result in a rapid decrease of the pH of the polishing solution and can in certain cases of semiconductor materials such as silicon have the result that the size of the abrasive particles is increased by agglomeration and that there is thus a risk of abrasion damage because of these bulkier particle agglomerations.

An embodiment example of the use of planarization of a layer is presented here in the case where the layer to be planarized at least partially includes silicon.

The solution suitable for polishing silicon is generally a basic solution with pH between 7 and 10, preferably between 8 and 10, the chemical agent then preferably being a nitrogenous base such as ammonia.

The abrasive particles are preferably silica molecules with particle sizes of the order of a tenth of a micron.

If it is decided to rinse, a surfactant will be used with a pH preferably between 3 and 5, or even around 4, with a CMC (Critical Micellar Concentration) of about 0.1% or less.

The time of the rinsing step will advantageously be
of the order of 50% of the polishing time.

These mechanical or mechano-chemical means are particularly advantageous in the context of the invention for controlling the quantity of material removed, so as to permit preserving at least a portion of the taking-off structure I.

But generally the removal of substance from the donor wafer 10 can include the use of any mechanical means for attacking material, such as for example lapping or bombardment with atomic species.

This removal of substance can if necessary be preceded by a heat treatment permitting further smoothing of the surfaces to be removed.

Referring to Figure 1c, the portion of the original buffer structure which remains after the removal of substance is given the reference I'.

It will be preferred firstly and in certain cases to perform finishing of the surface state of the donor wafer 10 in the region of which the removal of

substance took place which was effected during the first recycling step, so as to remove any roughness which could have appeared during the removal of substance.

For this purpose, a heat treatment will be performed, for example.

An example illustrated of an overall taking-off method comprising taking off a thin layer and recycling the donor wafer 10 after recycling is given by reference to Figures 1a-1d.

Referring to Figure 1a and as previously substantiated, the taking-off structure I has a thickness greater than or equal to two useful layers.

A thin layer taking-off method is illustrated in Figures 1b and 1c.

A first preferred taking-off step of the invention consists in creating an embrittlement zone in the taking-off structure I, in order to effect a later detaching, and thus to take off the desired layer(s).

Several techniques which can be implemented for the creation of such an embrittlement zone are presented here:

A first technique, called Smart-Cut®, known to those skilled in the art (and of which descriptions can be found in a number of works concerning wafer reduction) consists, in its first step, in implanting atomic species (such as hydrogen ions) with a given energy for thus creating an embrittlement zone.

A second technique consists of forming a fragile interface by the creation of at least one porous layer, as described for example in the document EP-A-0 849 788.

Referring to Figure 1b, a second step concerning the taking-off of a thin layer consists in applying a receiving substrate 2 to the surface of the donor wafer 10.

The receiving substrate 2 constitutes a mechanical support which is sufficiently rigid to support the second layer 3, a portion of which will be taken off from the donor wafer 10, and to protect it from possible mechanical stresses coming from the exterior.

This receiving substrate 2 may be, for example, silicon, quartz, sapphire, SiC, or another type of material.

The receiving substrate 2 is applied by placing it in intimate contact with the taking-off structure I and in bringing about bonding, in which molecular adhesion is advantageously effected between the substrate 2 and the taking-off structure I.

This technique of bonding, as well as alternatives, is in particular described in the document entitled "Semiconductor Wafer Bonding" (Science and Technology, Interscience Technology) by Q.Y. Tong, U. Gösele and Wiley.

The bonding is accompanied, if necessary, by an appropriate preliminary treatment of the respective surfaces to be bonded and/or a supply of thermal energy and/or the provision of a supplementary bonding agent.

Thus, for example, a heat treatment performed during or just after bonding enables the bonds to be rigidified. Bonding can also be controlled by a bonding layer, such as silica, intercalated between the taking-off structure I and the receiving substrate 2 and capable of particularly strong molecular bonding.

Advantageously, the material constituting the bonding face of the receiving substrate 2 and/or the material of the bonding layer formed if necessary, is electrically insulating for forming an SeOI structure starting from the taken-off layers, the layer of semiconductor of the SeOI structure then being the taken-off portion (i.e., the useful layer) of the taking-off structure I.

Once the receiving substrate 2 is bonded, a removal of the portion of the donor wafer 10 is performed in the region of the previously formed embrittlement zone, by effecting detaching there.

In the case of the said first technique (Smart-Cut®), the implanted zone (forming the embrittlement zone) is subjected in a second step to a thermal and/or mechanical treatment, or other provision of energy, to effect detaching in the region of the embrittlement zone.

In the case of the said second technique, the fragile layer is subjected to a mechanical treatment or other supply of energy to effect detaching in the region of the embrittlement zone.

Detaching in the region of an embrittlement zone according to one of these two techniques permits removal of a major portion of the wafer 10 to obtain a structure comprising the remainder of the taken-off taking-off structure I (which thus represents the useful layer here), the possible bonding layer, and the receiving substrate 2.

A post-taking-off structure I' constitutes the portion of the taking-off structure I remaining after taking-off, the whole of the wafer forming a donor wafer 10' to be sent to recycling for later re-use during a taking-off of a later layer.

The result of recycling of such a donor wafer 10' is shown in Figure 1d.

It performs a mechanical or mechano-chemical attack of the post-taking-off structure I' according to one of those already discussed hereinabove, to remove a portion of the post-taking-off structure I'.

Several techniques for the removal of substance by different mechanical means can also be implemented here, particularly if the post-taking-off structure I' comprises several layers of different origin, such as for example using successive attacks by CMP and by simple polishing.

This mechanical attack of material can be preceded and/or followed by surface treatments, such as chemical etching, heat treatment, or smoothing.

Referring to Figure 1d, the taking-off structure I" obtained after recycling is substantially identical to the taking-off structure I, reduced by a thickness close to the mean thickness of the layer which has been taken off and of the material removed during recycling. According to the invention, this thickness is sufficient to comprise a useful layer which can be taken off.

The donor wafer 10" is then suitable for providing a taken-off useful layer in the taking-off structure I" during a later taking-off without any other supplementary step such as a step of crystalline growth.

In a specific configuration of the donor wafer 10 before taking-off, the said wafer comprises a plurality of useful layers which can be taken off.

In this specific configuration, and for a taking-off structure I according to the invention in which several useful layers can be taken off between recycling steps according to the invention, in an advantageous context a cyclic method is used, of taking off useful layers from a donor wafer 10 according to the invention, while iteratively performing in succession:

- a taking–off process, and
- a recycling process according to the invention.

Before the implementation of the cyclic taking-off process, a process of forming the donor wafer 10 according to the invention can be performed, with one or more of the techniques of formation of thin layers on substrate 1 described hereinabove.

The possibility of taking off several times according to the present invention, starting from a donor wafer 10, in a same structure I formed on substrate 1 without necessarily forming supplementary layers there and/or without necessarily performing a treatment for recovering at least a portion of the substrate 1, permits a gain of time of the implementation of the overall taking-off method, an easier implementation of the method, and a substantially less elevated economic cost than the different methods of the prior art.

After a certain number of takings-off and of recyclings performed in the taking-off structure I, the number of takings-off being in particular a function of the thickness of the latter, the remaining taking-off structure I is no longer sufficiently thick to contain a useful layer to be taken off.

The donor wafer 10 is then only constituted by about nothing more than the substrate 1.

In a first case, the donor wafer 10 is discarded, and the whole of the substrate 1, which may be complex, long and costly to produce, particularly in the case where the substrate 1 includes a buffer structure, is then lost.

In a second, more advantageous, case, at least a portion of the substrate 1 is recovered, by implementing a recycling method.

In the case in which the substrate 1 includes a buffer structure, three types of recycling of the substrate 1 can be implemented:

- recycling comprising the removal of the whole of the buffer structure, but permitting preservation of at least a portion of the support substrate on which the buffer structure was formed; this recycling always entails the loss of the portion of the substrate 1 generally the most difficult and the most costly to form; and necessitates the implementation of a supplementary step of reformation of a buffer structure if it is desired, for example, to reform a substrate 1 equivalent to that before recycling;

- recycling including the removal of a portion of the buffer structure, and permitting preservation of the support substrate on which the buffer structure was formed, and a portion of the buffer structure, such as a buffer layer which is costly to produce; during recycling, there could be performed, for example and advantageously, a selective removal of substance stopped by a stop layer judiciously situated in the buffer structure; a supplementary step of reforming a buffer structure is advantageously implemented if it is desired, in particular, to reform a substrate 1 equivalent to that before recycling;

- recycling, including the removal of at least a portion of the remainder of the original taking-off structure I, and permitting the whole of the substrate 1 to be preserved; during recycling a step could be implemented for surface finishing the rest of the taking-off structure I (for example by CMP, heat treatment, sacrificial oxidation, bombardment, or other smoothing technique) and/or performing a selective removal of substance, stopped by a stop layer, for example judiciously situated between the taking-off structure I and the substrate 1;

After recycling the substrate 1, a new taking-off structure I is then reformed, in which several useful layers can be taken off according to a method of the invention.

This new taking-off structure I may be substantially identical to that before recycling.

This new taking-off structure I could have a structure slightly different from that of the taking-off structure I before recycling, by slightly modifying

certain parameters of formation. For example, concentrations of certain compounds in a material will be slightly modified.

In any case, the taking-off structure is advantageously formed by layer growth, for example by epitaxy by CVD or MBE.

In a first case, the growth of at least one of the layers comprised in the taking-off structure I is formed in situ, directly in continuation of the formation of the underlying support layer, the latter also being advantageously formed by layer growth in this case.

In a second case, the growth of at least one of these layers is performed after a light step of surface finishing of the underlying growth support, for example by CMP polishing, heat treatment, or other smoothing technique.

In what follows in this document, we present examples of configurations of donor wafers 10 comprising structures I with several layers, and capable of being used by a method according to the invention.

Specifically, we will present materials which can advantageously be used in such donor wafers 10.

For certain of the examples detailed, the substrate 1 comprises a buffer structure and a support substrate, the buffer structure being formed on the support substrate.

The buffer structure then possesses, in the examples concerned, a first lattice parameter in the region of its support substrate and a second lattice parameter in the neighbourhood of its interface with the overlying taking-off structure I.

Such a buffer structure comprises a buffer layer permitting such an adaptation of the lattice parameter to be performed.

The first method of forming a buffer structure (as discussed hereinabove) most often used for obtaining a buffer layer having this property is to have a buffer layer composed of several atomic elements comprising:

- at least one atomic element found in the composition of the support substrate, and

▪ at least one atomic element not, or scarcely, found in the support substrate, and having a concentration progressing gradually in the thickness of the buffer layer.

The graded concentration of this element in the buffer layer will be the principal cause of the gradual progression of the lattice parameter in the buffer layer in a metamorphic manner.

Thus, in this configuration, a buffer layer is principally an alloy.

The atomic elements chosen for the composition of the support substrate for the buffer substrate and of the buffer layer may be of Group IV type, such as Si or Ge.

For example, there could be in this case a support substrate of Si and a buffer layer of SiGe, with a Ge concentration progressively evolving with a thickness between a value near 0 at the interface with the support substrate and a specific value on the other face of the buffer layer.

In another case shown, the composition of the support substrate and/or of the buffer layer may comprise a pair of atomic elements of Groups III-V, such as a pair chosen from among the possible combinations (Al, Ga, In) – (N, P, As).

For example, there could be in this case a support substrate of AsGa and a buffer layer comprising As and/or Ga with at least one other element, the latter element evolving progressively with a thickness from a value near 0 at the interface with the support substrate and a specific value on the other face of the buffer layer.

The composition of the support substrate and/or of the buffer layer can comprise a pair of atomic elements of Groups II-VI, such as a pair chosen from among the possible combinations (Zn, Cd) – (S, Se, Te).

We present hereinafter several examples of such configurations:

The first three examples deal particularly with donor wafers 10 comprising a substrate 1 of Si and a buffer layer of SiGe and other layers of Si and of SiGe.

These wafers 10 are particularly useful in the case of taking off layers of SiGe and/or of stressed Si for forming SGOI, SOI, or Si/SGOI structures.

We present hereinafter several examples of such configurations:

Example 1: The donor wafer 10 is constituted:

- by a substrate 1 constituted:
  - ✓ by a support substrate of Si
  - ✓ by a buffer structure of SiGe formed according to the said first technique of buffer structure formation, comprising a buffer layer and an additional layer;
- by a taking-off structure I comprising SiGe and possibly one or more fine layers of elastically stressed Si.

The buffer layer preferably has a Ge concentration which progressively increases from the interface with the support substrate, to cause the lattice parameter of the SiGe to progress as explained hereinabove.

The thickness is typically comprised between 1 and 3 micrometers to obtain a good structural relaxation at the surface, and to confine defects related to the difference of lattice parameter so that they are buried.

The additional layer is of SiGe, substantially relaxed by the buffer layer, with an advantageously uniform Ge concentration, substantially identical to that of the buffer layer in the neighbourhood of their interface.

The concentration of germanium in the silicon within the relaxed SiGe layer is typically comprised between 15% and 30%.

This limitation to 30% represents a typical limitation of the present techniques, but may be made to progress during the coming years.

The additional layer has a thickness which may greatly vary according to the case, with a thickness typically comprised between 0.5 and 1 micron.

Example 2: The donor wafer 10 is constituted:

- by a substrate 1 constituted:
  - ✓ by a support substrate of Si;

✓ by a buffer structure formed according to the said first technique of forming a buffer structure comprising a buffer layer of SiGe and an additional Ge layer;

- by a taking-off structure I comprising before taking-off, AsGa and/or AlGaAs.

The buffer layer preferably has a Ge concentration progressively increasing from the interface with the support substrate, to cause the lattice parameter to progress between that of the Si support substrate and that of the Ge additional layer.

For this purpose, the Ge concentration in the buffer layer is caused to progress from about 0 to about 100%, or more precisely around 98%, for a theoretically complete agreement with the lattice of the two materials.

Example 3: The donor wafer 10 is constituted:

- by a substrate 1 constituted by Si;
- by a taking-off structure I comprising, before taking-off, Si and possibly one or more fine layers of elastically stressed SiGe.

-

Example 4: The donor wafer 10 is constituted:

- by a substrate 1 constituted:
  - ✓ by a support substrate of Si;
  - ✓ by a buffer layer formed according to the said second specific technique of formation of a buffer structure discussed hereinabove and disclosed by the document WO 00/15885, that is, by:
    - a deposition of a first layer of Ge or SiGe according to the said second specific technique of formation of a buffer structure discussed hereinabove and disclosed by the document WO 00/15885,
    - possibly followed by a deposition of an optional second layer, capable of improving the crystallographic quality of the overlying layer, as disclosed in the document WO 00/15885, the second layer being of:
      - o SiGe (50/50) in the case where the first layer of the buffer layer is of Ge;

- stressed Si in the case where the first layer of the buffer layer is of SiGe;

✓ a taking-off structure I comprising at least one of the following materials: Ge, SiGe, Si.

The taking-off in the taking-off structure I can concern a set of layers or a single layer of the taking-off structure I.

It will be noted that the structures obtained at the end of a taking-off according to this example are free from defects of the dislocation type, even in a buried region.

And the structures obtained of this kind can then be used for epitaxially growing supplementary layers, for example of stressed silicon, on the layer of SiGe, Ge, or Si.

Example 5: The donor wafer 10 is constituted by:

- a substrate 1 comprising:

✓ a support substrate of Si;

✓ a buffer layer of Si, formed according to the said third technique of formation of a buffer structure;

✓ a taking-off structure I comprising at least one of the following materials: SiGe, Si.

This donor wafer 10 is the wafer obtained after the formation of the buffer layer according to the said third technique of forming a buffer structure.

In a first embodiment of the buffer layer, the taking-off structure I was present before the formation of the buffer layer.

The taking-off structure before taking-off advantageously has a density of defects, such as dislocations, less than about 10^7 cm^{-2}.

The typical thicknesses of a taking-off structure before taking-off, of SiGe with 15% Ge and of a taking-off structure before taking-off, of SiGe with 30% Ge, are respectively about 250 nm and about 100 nm, thus remaining below their respective final critical thicknesses of elastic stress.

According to what has been seen hereinabove, a buffer layer is formed according to two principal steps:

- formation of a zone of perturbation in the support substrate 1 of Si by implantation of atomic species such as H or He;
- heat treatment to cause at least a relative relaxation of the elastic stresses in the taking-off structure.

During the first step, the ranges of implantation energies of H or He used are typically between 12 and 25 keV.

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

➢ Thus, for example, for a taking-off structure with 15% Ge, H will preferably be used, with an implant dose around $3 \cdot 10^{16}$ cm^{-2} at an energy around 25 keV.

➢ Thus, for example, for a taking-off structure with 30% Ge, H will preferably be used, with an implant dose around $2 \cdot 10^{16}$ cm^{-2} at an energy around 18 keV.

The implant depths of the atomic species in the substrate 1 are then typically between about 50 nm and 100 nm.

The heat treatment performed during the second step should be suitable for markedly increasing the number and amplitude of perturbations in the region situated between the perturbation zone and the taking-off structure. This region in which the perturbations are displaced will then form the said buffer layer.

The appearance of dislocations in the buffer layer then causes an overall relaxation of the taking-off structure.

The heat treatment is preferably performed under an inert atmosphere. However, the heat treatment can be performed under another atmosphere, such as for example an oxidizing atmosphere.

Thus, a specific heat treatment to be performed for this type of donor wafer 10 is carried out at temperatures typically comprised between 400°C and 1,000°C for a time which can be between 30 s and 60 minutes, and more specifically about 5 minutes to about 15 minutes.

In a second embodiment of the buffer layer, the buffer structure I is not present before the formation of the buffer layer, the donor wafer then advantageously appearing in the following form:

- a substrate 1 of Si;
- a layer of SiGe with at least 15% of Ge, the SiGe being elastically stressed.

The techniques and parameters of relaxation of this SiGe layer are substantially identical to those of the first embodiment of the buffer layer.

After formation of the buffer layer, layers constituting the taking-off structure I comprising the overall relaxed layer or set of layers.

The taking-off structure I is thus formed after the buffer layer, contrary to the first embodiment proposed in this example.

For more details as regards such experimental techniques, reference will be made to the studies carried out by B. Höllander et al., particularly 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).

After bonding of the wafer 10 to a receiving substrate 5, taking-off is performed with or without intermediate bonding layer, according to one or more known techniques, previously described, and the wafer is then recycled according to the invention.

Example 6: The donor wafer 10 is constituted:

- by a substrate 1 constituted:
  - ✓ by a support substrate comprising at least one portion of AsGa in the region of its interface with the overlying buffer structure;
  - ✓ a buffer structure of III-V material formed according to the said first technique of formation of a buffer structure;
- by a taking-off structure I comprising a III-V material before taking-off.

The main purpose of this buffer structure is to adapt the lattice parameter to the material of the taking-off structure I in the neighbourhood of their interface (which is for example a nominal value of about 5.87 angstroms in the case of InP) to that of AsGa (the nominal value of which is about 5.65 angstroms)

In the solid III-V materials, the practical interest of such a buffer structure may appear, for example, in the light of a comparison between different materials such as solid InP and solid AsGa, solid AsGa being for example less costly, more available on the semiconductor market, less mechanically fragile, with already known implementation of rear face contact technologies, and with larger sizes (typically 6 inches instead of 4 inches for solid InP) than solid InP.

However, the electronic performance of InP is as a general rule better than that of AsGa.

Thus, the said donor wafer 10 gives, for example, a solution to the formation of a layer of InP dimensioned to 6 inches by proposing a taking-off structure I comprising InP formed on an AsGa support substrate and relaxed by means of a buffer structure.

Thus there is seen here all the advantage which such a donor wafer 10 can offer: it permits an active layer of a III-V material to be formed, for transfer with a given quality and properties, capable for example of being close to the properties which would have been found in an embodiment of the said solid material.

The buffer structure comprised in such a donor wafer 10 necessitates a thickness typically greater than one micron, and which can be brought to progress toward greater thicknesses, particularly if destroying it after each taking-off can be avoided, specifically by means of a recycling method according to the present invention.

In the example of a taking-off structure I comprising essentially relaxed InP in the region of its interface with the underlying buffer structure, the buffer structure of the substrate 1 then advantageously comprises a buffer layer

constituted of InGaAs with an In concentration progressing between 0 and about 53%.

The buffer structure may furthermore comprise an additional layer of III-V material, such as InGaAs or InAlAs, with a substantially constant concentration of the atomic elements.

In a particular case of taking-off, at least one InP layer will be taken off the taking-off structure I for transfer to a receiving substrate 2.

The advantage of possible electrical or electronic properties can thus be attained.

It is for example the case if the portion taken off furthermore comprises InGaAs or InAlAs: discontinuities of electronic bands between the latter material and InP notably create better electron mobilities in the taken-off layers.

Other configurations of donor wafers 10 are possible, comprising other III-V compounds.

The applications of such taking-off of layers are typically embodiments of HEMT or HBT (High Electron Mobility Transistor and Heterojunction Bipolar Transistor).

Example 7: The donor wafer 10 is constituted:

- by a substrate 1 constituted:
  - ✓ by a support substrate comprising AsGa in the region of its interface with the overlying buffer structure;
  - ✓ by a buffer structure formed according to the said first technique of buffer formation, and comprising InGaAs in the region of its interface with the taking-off structure I;
- by a taking-off structure I comprising, before taking-off, InP and/or $In_xGa_{1-x}As_yP_{1-y}$.

This type of donor wafer 10 has already been described in Example 6.

Example 8: The donor wafer 10 is constituted:

- by a substrate 1 constituted:

✓ by a support substrate of sapphire or of SiC or of Si;

✓ by a buffer structure formed according to the said first technique of formation of a buffer layer, constituted:

• by a metamorphic buffer layer of $Al_xGa_{1-x}N$, x varying with thickness from 0 to 1 starting from the interface with the sapphire;

• by an additional layer of GaN intended to confine dislocation-type crystallographic defects;

- by a taking-off structure I comprising layers of nitrides.

The III-V nitrides GaN, AlN and InN are of interest in the field of microelectronics, specifically in the light emitting devices such as lasers for applications such as the reading and writing of data stored at high densities on compact discs or such as electroluminescent diodes for new display technologies. These materials are also all designated for the manufacture of electronic components of high power or operating at high temperature.

A mode of formation of layers of nitrides comprised in the taking-off structure I is epitaxial growth on the additional GaN layer by deposition of organometallic compounds of Group I, such as trimethyl gallium, trimethylamine alane, or trimethyl indium for respective deposition of layers of GaN, AlN and InN.

The present invention, when used for transferring several of these nitride layers from the same donor wafer 10 involves a recycling step between each layer taking-off, permitting the preparation of another layer of the taking-off structure I for another taking-off.

Example 9: The donor wafer 10 is constituted:

- by a substrate 1 constituted:

✓ by a support substrate of sapphire or SiC or Si;

✓ by an intermediate layer of GaN;

✓ by a mask of SiO_2;

✓ by a buffer layer of GaN;

- by a taking-off structure I comprising a layer, or set of layers, of nitride of which at least one layer is of GaN.

The mode of formation of the buffer layer is that already described hereinabove, in the description of the said fourth technique of forming a buffer layer, and consists of bringing about anisotropic growth of successive layers of nitrides, specifically GaN here, according to the ELOG technique.

The SiO_2 mask used in this configuration advantageously has the form of bands disposed on the intermediate layer of GaN in a periodic manner and substantially mutually parallel.

The thickness of each band is typically of the order of several tenths of a micron, while the width of a band is of the order of several microns.

The period spacing the bands apart is typically around 10 microns or 15 microns.

For example, there could be a band system of period 13 microns, each band having 0.2 microns thickness and 5 microns width.

As explained above in a general case, these SiO_2 bands will cause dislocations, localized in the neighbourhood of the free surface of these bands, in the layer(s) of GaN deposited above them.

The thickness of GaN in which these dislocations are localized around the mask then constitutes the said buffer layer.

The layers of GaN or other materials having lattice parameters close to GaN are deposited on the buffer layer to form the said taking-off structure I.

This taking-off structure I then comprises at least two layers, each having a thickness equal to or greater than the thickness of a useful layer which it is desired to take off.

For more details of the mode of forming a wafer according to the LOG method, reference can be made to the document taken from the "MRS Bulletin" of May 1998, Volume 23, No. 5, at the article of Shuji Nakamura entitled "In/GaN/AlGaN-Based Laser Diodes with an Estimated Lifetime of Longer than 10,000 Hours".

Layers of InN can in particular be integrated into this taking-off structure I during the course of its formation, as previously described in Example 8.

Other constituents can be added to the semiconductor layers mentioned in this document, such as carbon with a carbon concentration in the considered layer substantially equal to or less than 50%, or more particularly with a concentration equal to or less than 5%.

Finally, the present invention is not limited to a donor wafer 10 of materials mentioned in the examples hereinabove, but also extends to other types of materials belonging to Groups II, III, IV, V or VI and to alloys belonging to Groups IV-IV, III-V, or II-VI.

It should be mentioned that in the case of alloy materials, the alloys chosen can be binary, ternary, quaternary, or of higher degree.

In the case in which the donor wafer 10 includes a buffer layer or a buffer structure, the present invention is not limited to a buffer layer or buffer structure having as primary function an adaptation of the lattice parameter between two adjacent structures having respective different lattice parameters, but also concerns any buffer layer or buffer structure such as defined in the most general manner in this document.

The structures finally obtained starting from the taking-off of a useful layer are also not limited to SGOI, SOI, or Si/SGOI structures, to HEMT and HBT structures for transistors, or to structures for applications in lasers.

CLAIMS

1. Method of recycling a donor wafer after having taken off a useful layer comprising a material chosen from semiconductor materials, the donor wafer comprising successively a substrate and a taking-off structure, the taking-off structure before taking-off comprising the useful layer to take off, the method comprising removal of substance on the side where the taking-off took place, characterized in that the removal of substance comprises employing mechanical means so that, after removal of substance, at least a part of the taking-off structure remains, this at least part of the taking-off structure including at least one other useful layer that can be taken off after recycling, without a supplementary step of reforming a useful layer.

2. Method of recycling a donor wafer according to the previous claim, characterized in that the employing of mechanical means during the removal of substance comprises polishing.

3. Method of recycling a donor wafer according to claim 1, characterized in that the employing of mechanical means during the removal of substance comprises abrasive polishing.

4. Method of recycling a donor wafer according to one of the previous claims, characterized in that the employing of mechanical means during the removal of substance is accompanied by chemical etching.

5. Method of recycling a donor wafer according to claim 1, characterized in that the removal of substance including the employing of mechanical means comprises a chemical and mechanical planarization (CMP).

6. Method of recycling a donor wafer according to one of the previous claims, characterized in that the employing of mechanical means is preceded by, and/or followed by, a surface finishing treatment.

7. Method of recycling a donor wafer according to the previous claim, characterized in that the surface finishing treatment comprises a heat treatment.

8. Method of recycling according to one of the previous claims, characterized in that the substrate comprises a buffer layer located between the support substrate and the taking-off structure, the buffer layer being of crystalline material having a constant chemical composition and a lattice mismatch with the support substrate, so that it confines crystallographic defects.

9. Method of recycling according to the previous claim, characterized in that the buffer layer is of Si, SiGe, Ge, or nitride material, and in that the taking-off structure comprises at least one of the following materials: elastically stressed Si, SiGe or Ge or nitride material.

10. Method of recycling according to one of the to claims 1 to 7, characterized in that the substrate comprises a support substrate and a buffer structure with a lattice parameter varying substantially and progressively through its thickness between the lattice parameter of the support substrate and another lattice parameter substantially different from the lattice parameter of the support substrate.

11. Method of recycling according to the previous claim, characterized in that the buffer structure further comprises an additional layer on the buffer layer, the additional layer having:

- a sufficiently great thickness to confine defects; and
- a surface lattice parameter substantially different from that of the support substrate.

12. Method of recycling according to one of the two previous claims, characterized in that the buffer structure and the taking-off structure both comprise atomic alloy belonging to one of the following atomic alloy Groups:

- Group IV-V;
- Group III-V;
- Group II-VI;

this alloy being of a binary, ternary, quaternary, or higher degree type.

13. Method of recycling according to one of claims 1 to 7, characterized in that the donor wafer comprises:

- in a first configuration:
  - √ a support substrate constituted by Si;
  - √ a buffer structure comprising a buffer layer of SiGe with a Ge concentration which increases in thickness and an additional layer of SiGe, relaxed by the buffer layer;
  - √ a taking-off structure comprising, before taking-off, SiGe and/or Ge; or
- in a second configuration:
  - √ a support substrate constituted by Si;
  - √ a buffer structure comprising a buffer layer of SiGe with a Ge concentration which gradually increases in thickness between about 0% and about 100% and an additional layer of Ge, relaxed by the buffer layer;
  - √ a taking-off structure comprising, before taking-off, AsGa and/or Ge; or
- in a third configuration:
  - √ Si at least over a thick portion interfaced with the taking-off structure;
  - √ a taking-off structure comprising, before taking-off, Si; or
- in a fourth configuration:
  - √ a support substrate comprising AsGa in the region of its interface with the buffer structure;
  - √ a buffer structure comprising a buffer layer comprising an atomic alloy of ternary or higher degree type, belonging to Group III-V, the composition of which is respectively chosen from among the possible combinations (Al, Ga, In) - (N, P, As), and at least two elements chosen from Group III or at least two elements chosen from Group V, these two elements having a concentration evolving gradually in the thickness of the buffer layer;
  - √ a taking-off structure comprising, before taking-off, an alloy belonging to Group III-V; or

- in a fifth configuration: the same layers and the same materials as those of the fourth configuration, with:
  - √ a buffer structure having a lattice parameter similar to that of InP close to the face opposite to its interface with the support substrate;
  - √ a taking-off structure comprising, before taking-off, InP and/or InGaAs; or
- in a sixth configuration:
  - √ a support substrate of sapphire or of SiC or of Si;
  - √ a buffer layer of $Al_xGa_{1-x}N$, with x varying from 0 to 1 starting from the interface with the support substrate;
  - √ possibly an additional layer of GaN;
  - √ a taking-off structure comprising, before taking-off, InP and/or InGaAs; or
- in a seventh configuration:
  - √ a support substrate of sapphire or of SiC or of Si;
  - √ possibly a layer of GaN;
  - √ a mask;
  - √ a buffer layer of GaN;
  - √ a taking-off structure comprising, before taking-off, GaN and possibly other nitrides.

14. Method of recycling according to the previous claim, characterized in that the taking-off structure furthermore comprises:

- in the first configuration: elastically stressed Si;
- in the third configuration: elastically stressed SiGe.

15. Method of recycling according to one of the previous claims, characterized in that the donor wafer comprises at least one layer furthermore including carbon with a carbon concentration in the layer substantially equal to or less than 50%.

16. Method of recycling according to one of the previous claims, characterized in that the donor wafer comprises at least one layer

furthermore including carbon with a carbon concentration in the layer substantially equal to or less than 5%.

17. Method of taking-off a useful layer from a donor wafer by transferring it to a receiving substrate, characterized in that it comprises:

(a) bonding the donor wafer to the receiving substrate on the side of the useful layer to be taken off;

(b) detaching the useful layer comprised in the taking-off structure of the donor wafer;

(c) recycling *the* donor wafer according to the method according to one of claims 1 to 16.

18. Method of taking-off a useful layer according to the previous claim, characterized in that it further comprises, before the step (a), the formation of a bonding layer.

19. Method of taking-off a useful layer according to one of the two previous claims, characterized in that:

- it further comprises, before step (a), a formation of an embrittlement zone situated beneath the useful layer, and in that:

- step (b) is performed by supplying energy to the region of the embrittlement zone for detaching from the donor wafer a structure comprising the useful layer.

20. Method of taking-off a useful layer according to the previous claim, characterized in that the formation of the embrittlement zone is performed by implantation of atomic species.

21. Method of taking-off a useful layer according to the previous claim, characterized in that the implanted atomic species comprise hydrogen and/or helium.

22. Method of taking-off a useful layer according to claim 19, characterized in that the embrittlement zone is formed by porosification.

23. Method of taking-off a useful layer according to one of claims 17 to 22, characterized in that it comprises, after step (b), a step of surface finishing on the useful layer in the region of which detaching took place.

24. Method of cyclic taking-off of a useful layer from a donor wafer , characterized in that it comprises a succession of steps of taking-off of a useful layer, each of these steps being complying with the method of recycling according to one of claims 17 to 23.

25. Application of a method of cyclic taking-off according to one of the previous claim or of a method of taking-off according to one of claims 17 to 23, to the formation of a structure comprising the receiving substrate and the useful layer, the useful layer comprising at least one of the following materials:

SiGe, Si, an alloy belonging to Group III-V whose composition is respectively chosen from among the possible combinations (Al, Ga, In) - (N, P, As).

26. Application of a method of cyclic taking-off according to claim 24 or of a method of taking-off according to one of claims 17 to 23, to the formation of a semiconductor-on-insulator structure, the structure comprising the receiving substrate and the useful layer, the useful layer being at least a portion of the semiconductor layer of the semiconductor-on-insulator structure.

27. Donor wafer having provided a useful layer by taking-off, and capable of being recycled by a method according to one of claims 1 to 16, characterized in that it successively comprises a substrate and a remaining part of the taking-off structure having provided the useful layer, and in that, after taking-off, the remaining part of the taking-off structure is still sufficiently thick for comprising at least one other useful layer to be taken-off.

28. Donor wafer according to the previous claim, characterized in that the substrate comprises a support substrate and a buffer structure, the buffer structure being situated between the support substrate and the remaining part of the taking-off structure.