Process for fabricating a heterostructure comprising at least one thick film of semiconductor material

The present invention relates in general to the fabrication of materials and more particularly for the fabrication of heterosubstrates for use in microelectronics, optoelectronics, optics or photonics.

More precisely, the invention relates to a novel process for producing a heterosubstrate composed of at least one support and one or more thin films, in which the materials used and their thermal properties may be different.

Processes of this type are already known.

Thus, it is known to produce heterosubstrates employing bonding techniques, in particular molecular adhesion (hereinafter called "direct bonding") techniques.

Nonlimiting examples of known processes using a bonding step include those of the Besoi®, Eltran® or Smart Cut® type.

In general, the context of fabricating heterosubstrates, said processes comprise at least the following steps:

a) bonding by contacting of two generally bulk substrates made up in general of dissimilar materials, with a useful film that lies on a support substrate, the whole assembly forming a heterostructure;

b) reinforcement of the bonding interface between the two substrates by applying a high-temperature heat treatment to reduce the weakness of said interface - problems of delamination and impairment of the mechanical and/or electrical quality of said useful film are thus avoided, or at the very least limited; and

c) reduction of the thickness of the useful film lying on the support substrate so as to constitute a thin film.

Such steps may be employed with various options, such as, for example, a sacrificial oxidation in step c), or with a different order, in particular with steps b) and c) reversed.

Moreover, some of these steps may be combined for overall optimization of the process (cumulative duration of the treatments, cumulative duration associated with handling, etc.).

For example, a heat treatment for stabilizing the bonding film (step b)), may be applied to combine said heat treatment with a thinning step (step c)) (cf. patent US 6 403 450).

However, within the context of producing heterosubstrates with materials having different properties, for example, different thermal expansion coefficients, the heat treatments undergone by the composite substrate during the fabrication (for reinforcing the interface, for thinning, etc.) induce high mechanical stresses.

Such stresses may lead to embrittlement, and then in certain cases cracking or even fracturing, of one or both treated substrates.

These stresses may also lead to irremediable plastic deformation of the treated substrate(s).

In particular, dislocations and/or slip planes and/or other crystal defects may appear.

It is also known that the temperatures at which problems arise typically depend on:

- the mechanical energy stored by the composite structure during the heat treatment employed;
- the difference between the thermal expansion coefficients of the materials making up the composite structure; and
- the thickness of the substrates used.

Thus, within the context of fabricating heterosubstrates by a process of the Smart Cut® type, such problems may constitute real limitations.

More particularly, the maximum levels possible in terms of temperature decrease, so that it becomes difficult to apply heat treatments, for lack of effectiveness.

For example, but not exhaustively, a heat treatment for reinforcing an interface at around 1050-1000°C will be difficult to apply in the case of a heterostructure having a useful film 500 Å in thickness, the temperature levels generally employed in this type of treatment being too high as regards the abovementioned problems.

Moreover, solutions for improving the reinforcement of the bonding interface of a heterosubstrate without extra heat supply are known.

A first proposal, known as "plasma bonding", consists in applying certain treatments to the surfaces to be bonded in order to increase the bonding energy for a given reinforcing heat treatment.

By this way, the thermal stresses experienced by the substrates are relaxed, while maintaining suitable reinforcement and bonding of the interface in the composite structure.

However, this proposal requires specific equipment, thus limiting its attraction from the economic

standpoint.

A second known solution consists in carrying out eutectic bonding: a metallic (Au_2Si_3) film is interposed between the two substrates to be bonded, so as to make it easier to bond them by heat treatment, so that the temperature levels may remain relatively low.

This solution therefore offers the advantage of being able to relax the thermal stresses in a treatment while reinforcing the interface of a heterosubstrate.

However, the presence of said metallic film at the interface limits the maximum temperatures permitted during subsequent steps in the fabrication process, in which excessively high temperature levels may in fact result in the film melting. Furthermore, this solution requires an additional step of interposing this metallic film.

One object of the invention is to overcome the above problems.

For this purpose, the invention provides a process for fabricating a structure comprising at least one semiconductor material for applications in microelectronics, optoelectronics, optics, etc., the process comprising the transfer, onto a support made of a first material, of a single-crystal thin film made of a second material, different from the first, and a predetermined heat treatment for at least reinforcing a bonding interface between the thin film and the support, characterized in that the thickness of the thin film is chosen according to the difference between the thermal expansion coefficients of the first and second materials and according to the parameters of said predetermined heat treatment, in such a way that the stresses exerted by said heat treatment on the assembly, comprising the support and transferred thin

film, leaves said assembly intact and in that the process includes an additional step of depositing, on the thin film, a film of additional thickness of the second material in the single-crystal state.

Other preferred, but nonlimiting, aspects of the process according to the invention are the following:

* the thickness of the transferred thin film is between about 100 and 300 Å, preferably between 150 and 250 Å;

* the thickness of the film deposited on the transferred thin film is between 1000 and 5000 Å;

* the step of transferring the thin film of the second material comprises the substeps consisting in creating, in a donor wafer by implantation of species, a weakened zone having the boundary of the thin film to be transferred, in bringing the donor wafer into contact with the support and in applying stresses capable of leading to the detachment of the thin film from the rest of the donor wafer after the contacting operation;

* the process includes an additional step of preparing the free surface of the thin film, after detachment, in order to deposit the film;

* the deposition step is carried out by epitaxy;

* the first material is an insulator;

* the first material is quartz, while the second material is silicon;

* the first material is a semiconductor;

* the first material is silicon, while the second material is germanium; and

* said heat treatment is capable of generating in the transferred thin film an acceptable level of defects due to the difference between the thermal expansion coefficients of the first and second materials.

Other aspects, objects and advantages of the present invention will become more apparent upon reading the

following detailed description of preferred embodiments thereof given by way of nonlimiting example and with reference to the appended drawings, in which figures 1A to 1D illustrate schematically the main steps of a preferred process of the invention.

It will be noted here that the dimensions, in particular their relative thicknesses, shown in the figures have been chosen for the sake of clarity and are not supposed to illustrate the reality of the matter.

Referring first of all to figure 1A, this shows a support 10 and a donor wafer 20 in which a weakened zone 21 is produced, for example by ion implantation through a face 20a of the wafer, said zone marking the boundary of a zone 22 of the wafer 20 to be transferred onto the support 10.

In figure 1B, the support 10 and the wafer 20 are united and bonded together by direct bonding, a bonding interface film (not shown) such as an oxide or nitride film, optionally being formed on the support and/or on the wafer. The bonding interface is denoted by the reference 12.

The assembly then undergoes a heat treatment in one or more steps, so as, on the one hand to detach the zone 22 from the rest of the wafer 20 along the weakened zone and, on the other hand, to reinforce the bonding interface between the support 10 and the thin film now formed by the detached zone 22, as indicated above. The structure thus formed is illustrated in figure 1C.

The above steps correspond overall to the Smart Cut® process exploited by the Applicant.

The present invention is aimed at situations in which the material of the support 10 and the material of the

thin film 22 have thermal expansion coefficients sufficiently different from each other so that the aforementioned heat treatments cannot be carried out without the structure composed of the support 10 and the thin film 22, with the optional bonding interface films, suffering some deterioration.

According to the invention, a low value is chosen for the thickness e1 of the transferred film 22, such that the aforementioned heat treatments leave the structure substantially unaffected; in other words, the thickness of the film 22 is chosen to be sufficiently small not to cause any rupture, or undesirable plastic deformation, due for example to dislocations, slip of atomic planes, cracks, etc. in the film 22.

The free surface of the film 22 is then prepared for a film of the same material to be deposited thereon. This preparation may comprise chemical-mechanical polishing, sacrificial oxidation, RTA (Rapid Thermal Annealing), further furnace annealing, etc., the objective here being to end up with a surface of sufficiently low roughness.

The next step of the process, illustrated in figure 1D, consists in using the film 22 thus prepared as a seed film for depositing a film 22′ of the same material, with a thickness of e2, by epitaxy, and in increasing the thickness of the overall film 220 (useful film) of material constituting the films 22 and 22′ up to the desired value. Epitaxy allows good crystalline quality to be obtained.

It should here be pointed out that the choice of the thickness e1 of the transferred film 22 is chosen in such a way that it exists a certain density of dislocations or of slip planes in the intermediate heterostructure shown in figure 1C, and in particular in the transferred film 22. Indeed, such defects, after

epitaxial growth of the film 22' are buried depthwise in the useful film 220 and are not through-defects.

It will also be observed that the thickening phase, by epitaxial deposition of the film 22', makes it possible in the end to transfer much larger thicknesses than would be possible using a technique of the Smart Cut® type, which is inherently limited by the possible depth of implantation.

Example 1

The aim of this first example is to produce a structure composed of a quartz support, for example with the thickness of 1.2 mm, coated with a film of single-crystal silicon with a thickness that may reach 500 to 2000 Å for applications in microelectronics, or even higher for other applications, such as CCD (charge coupled device) applications.

It has been demonstrated by experiments that the critical temperature above which excessive plastic deformation occurs (by dislocations, slip planes, etc.) in a structure composed of a thin Si film transferred using the Smart Cut process onto a quartz support depends on the thickness of the transferred film as follows:

Thickness of film 22	Critical temperature
2000 Å	750°C
500 Å	950°C
200 Å	1100°C

In the present example, a single-crystal silicon film 22 with a thickness of 200 Å is transferred onto a quartz support 10, this transfer involving reinforcing the bonding interface by a heat treatment at 1050°C for a time of about two hours. Thanks to the limited thickness of the film 22, the structure suffers no prejudicial deterioration (cracking or fracture) due to

this heat treatment. The free surface of the thin film 22 is then prepared for the epitaxial deposition of the silicon complement for producing the single-crystal useful film in the desired thickness. This epitaxy is carried out so as to form the film 22', also made of single-crystal silicon, with a thickness that may vary widely depending on the application.

Thus, for applications in microelectronics, the thickness of the film 22' is for example about 800 to 1800 Å, so as to end up with a thickness of the useful film of 1000 to 2000 Å.

For CCD applications, the desired overall thickness is typically from 5 to 10 µm.

Example 2

The aim of this example is to produce a semiconductor-on-insulator structure comprising a support made of silicon (either single-crystal or polycrystalline silicon) and a thick useful film made of single-crystal germanium, for example, for applications in photovoltaic components.

The heat treatments required for detaching the thin germanium film 22 from its donor wafer and for reinforcing the bonding interface with the silicon support 10 are determined.

Typically, these treatments comprise a detachment phase at a temperature of about 300 to 400°C for a time of about a few minutes to two hours, and then a bonding interface reinforcing phase at a temperature of about 500 to 800°C for a time of about one hour.

Next, it is determined experimentally whether a thickness of the thin film 22, which does not exceed about 200 Å, does allow these heat treatments to be

applied to the structure without said thin film deteriorating.

Next, after a treatment preparatory to the epitaxy, such as a chemical-mechanical polishing step, has been carried out on the thin film 22, a single-crystal germanium film 22′ is then deposited in continuity with the film 22 in terms of crystal structure, therefore thickening the latter. In the present example, this film 22′ is deposited at a temperature of about 700°C and with a thickness of 4800 Å, in order to form in total a single-crystal useful germanium film with a thickness of 5000 Å or more (up to 3 μm).

Of course, the present invention is in no way limited to the embodiments described and a person skilled in the art will know how to make many variations thereto. The invention is applicable whenever it is desired to produce a heterostructure which includes at least one semiconductor material and in which an added film must have a thickness greater than that permitted by the essential starting data, namely the heat treatments to be undergone and the difference between the thermal expansion coefficients of the two materials. InP-on-Si and GaAs-on-Si structures may especially be mentioned.

It may also be pointed out that the transferred thin film may be strained, either in tension or in compression, the additional thickness of material provided by deposition retaining this strain. This allows thick strained films to be produced, the strains being provided over thicknesses of several tens of nanometers, or even up to several hundred nanometers, depending on the level of strain it is desired to maintain.

CLAIMS

1. A process for fabricating a structure comprising at least one semiconductor material for applications in microelectronics, optoelectronics, optics, etc., the process comprising the transfer, onto a support (10) made of a first material, of a single-crystal thin film (22) made of a second material, different from the first, and a predetermined heat treatment for at least reinforcing a bonding interface (12) between the thin film and the support, characterized in that the thickness (e1) of the thin film is chosen according to the difference between the thermal expansion coefficients of the first and second materials and according to the parameters of said predetermined heat treatment, in such a way that the stresses exerted by said heat treatment on the assembly, comprising the support and transferred thin film, leaves said assembly intact and in that the process includes an additional step of depositing, on the thin film, a film (22') of additional thickness of the second material in the single-crystal state.

2. The process as claimed in claim 1, characterized in that the thickness (e1) of the transferred thin film is between about 100 and 300 Å, preferably between 150 and 250 Å.

3. The process as claimed in claim 2, characterized in that the thickness (e2) of the film (22') deposited on the transferred thin film (22) is between 1000 and 5000 Å.

4. The process as claimed in one of claims 1 to 3, characterized in that the step of transferring the thin film (22) of the second material comprises the substeps consisting in creating, in a donor wafer (20) by

implantation of species, a weakened zone (21) having the boundary of the thin film to be transferred, in bringing the donor wafer into contact with the support and in applying stresses capable of leading to the detachment of the thin film from the rest of the donor wafer after the contacting operation.

5. The process as claimed in claim 4, characterized in that it includes an additional step of preparing the free surface of the thin film (22), after detachment, in order to deposit the film (22').

6. The process as claimed in one of claims 1 to 5, characterized in that the deposition step is carried out by epitaxy.

7. The process as claimed in one of claims 1 to 6, characterized in that the first material is an insulator.

8. The process as claimed in claim 7, characterized in that the first material is quartz.

9. The process as claimed in claim 8, characterized in that the second material is silicon.

10. The process as claimed in one of claims 1 to 6, characterized in that the first material is a semiconductor.

11. The process as claimed in claim 10, characterized in that the first material is silicon.

12. The process as claimed in claim 11, characterized in that the second material is germanium.

13. The process as claimed in one of claims 1 to 12, characterized in that said heat treatment is capable of generating in the transferred thin film (22) an

acceptable level of defects due to the difference between the thermal expansion coefficients of the first and second materials.