A METHOD FOR MANUFACTURING A HETEROSTRUCTURE AIMING AT REDUCING THE TENSILE STRESS CONDITION OF THE DONOR SUBSTRATE

The present invention relates to a method for making a heterostructure notably intended for applications in the fields of electronics, optics, photovoltaics, or optoelectronics.

This is more specifically a method which comprises the following steps:

- implantation of atomic species inside a first so-called "donor" substrate, so as to form an embrittlement area therein,
- assembly of a second so-called "receiver" substrate on the donor substrate,
- detachment of the rear portion of said donor substrate along the embrittlement area, so as to individualize a thin layer of interest on the receiver substrate.

A method of this kind is generally known under the trade mark of "Smart Cut".

By means of this technique, the specific advantages of the materials of the thin layer and of the support may be combined.

By transferring the layer, it is possible to associate in a same stack, portions which *a priori* have incompatibilities such as a large difference in the thermal expansion coefficient.

With such structures, one of the problems encountered during their manufacturing is due to the presence of a very strong stress field in the various layers in contact during a heat treatment such as the one during which detachment of the thin layer occurs. These stresses are due to the differential thermal expansion between the materials put into contact.

In such a case, it is essential to perform detachment at a lower temperature than the critical temperature at which the heterostructure will be degraded because of the stresses mentioned above. As the value of the stresses coming into play is related to the thickness of the assembled substrates, it will be noted that after

detachment of the layer, the structure may then be subject to more significant heat treatments.

The degradation which may occur during the manufacturing of the final structure is typically breakage of both substrates put into contact with each other and/or their detachment at the bonding interface.

Thus, in the case of the heterostructure of the silicon-on-sapphire (Al_2O_3) type, the thermal expansion coefficients (TECs) of silicon and of sapphire are $3.6x10^{-6}/°C$ and $5.0x10^{-6}/°C$, respectively. The differential expansion phenomenon first of all occurs at the moment of the heat treatment step intended to cause detachment of the thin layer from the silicon donor substrate.

In such a TEC difference situation, the transfer of the thin layer becomes delicate because the heat treatment steps (such as for example detachment annealing), which take place after adhesive bonding and before transfer, are necessarily limited. Indeed, the different expansion of both assembled substrates may lead to detachment of the assembly or to breakage of the substrate.

The invention is aimed at improving this state of the art.

More particularly, the invention is based on the observation, within the scope of a layer transfer method, notably by the Smart Cut technology, that during the assembling of a donor silicon substrate with a sapphire receiver substrate (and more generally when the thermal expansion coefficient (TEC) of a donor substrate is less than the TEC of a receiver substrate), the donor substrate is tensioned during heat treatments which follow the assembling and leading to fracture.

Now, it seems that the tensioned condition of the material of the donor substrate, in particular at the implanted area, is an obstacle to the propagation and/or development of “platelets” and other microscopic defects, precursors of the fracture phenomenon. More specifically, the orientation of the defects in this stressed material does not seem to occur along a beneficial direction, i.e. in the plane of the plate. This obstacle leads to faulty, delayed fracture or even completely blocked fracture.

The invention therefore provides a method for manufacturing a heterostructure notably intended for applications in the fields of

electronics, optics, photovoltaics or optoelectronics, which comprises the following steps:

- implantation of atomic species inside a first so-called "donor" substrate, so as to form an embrittlement area therein,
- assembly of a second so-called "receiver" substrate, on the donor substrate,
- detachment of the rear portion of said donor substrate along the embrittlement area so as to individualize, a thin layer of interest on the receiver substrate,

wherein said receiver substrate has a thermal expansion coefficient larger than that of the donor substrate, and which applies so-called “detachment” annealing after said assembly and before said detachment, in order to facilitate the latter.

This method is remarkable by the fact that said detachment annealing comprises simultaneous application:

- of a first temperature to the donor substrate;
- of a second temperature, different from the first, to the receiver substrate;

these first and second temperatures being selected so as to reduce the tensile stress condition of the donor substrate.

According to other advantageous and non-limiting features of the invention:

- it comprises a preliminary step which consists in forming or depositing an insulator layer on the donor substrate, so that there exists between them a so-called “binding” interface, and the assembling of the receiver substrate on the donor substrate is performed on the free surface of the insulator;
- the assembling of the receiver substrate on the donor substrate is performed by molecular bonding;
- said detachment annealing is accompanied and/or continued with application of mechanical forces;
- application of the first and second temperatures is performed in such a way that the whole of the volume of each substrate has a homogenous temperature;

- said first and second temperatures are applied by placing said structure between two heating electrodes;
- application of the first and second temperatures is performed by placing each substrate on an associated support brought to the corresponding temperature;
- a support associated with each substrate is used, which is an integral part of an adhesive bonding machine;
- said donor substrate is in silicon, while the receiver substrate is in sapphire, said first temperature being higher than the second;
- said first temperature is of the order of 300°C, while the second is of the order of 80°C.

Other features and advantages of the invention will become apparent upon reading the detailed description which follows of certain embodiments. This description will be made with reference to the appended drawings, wherein Figs. 1-3 illustrate the main steps of a method for manufacturing a heterostructure, according to the invention.

The method according to the invention repeats the traditional steps of a “Smart Cut” (registered trade mark) type method, as mentioned in the introduction of the present application.

However, the detachment annealing which induces detachment of the thin layer from the supporting substrate is conducted in a particular way.

This detachment annealing comprises the simultaneous application:

- of a first temperature to the donor substrate;
- of a second temperature different from the first to the receiver substrate;

these first and second temperatures being selected so as to reduce the tensile stress condition of the donor material.

Thus, in the case of the manufacturing of a silicon-on-sapphire (SoS) substrate, a temperature applied to the silicon substrate will be selected to be above the one applied to the sapphire substrate. The tensile stress applied to the structure is thereby reduced, as compared with the prior technique, and this therefore promotes or allows fracture.

Further, with the method according to the invention, it is possible to apply a higher temperature at the implanted area than in the prior technique (according to which a same temperature is applied to both substrates), because the deformation originating from the TEC difference of the assembled substrates is less and the breakage risk is more limited. With this, it is therefore possible to facilitate industrial application of the manufacturing method.

Moreover, with this higher temperature, it is possible to obtain a larger bonding energy between both substrates.

And reinforced bonding also contributes to improving the quality of the transferred layer, in particular if the substrates were assembled by molecular bonding.

Thus, it will be possible to obtain, by applying the method of the invention, a larger total transferred surface and a more regular contour of this surface, as compared with what may be obtained with the techniques from the prior art.

On this basis, the following exemplary embodiment may be applied.

A donor substrate 1 (see Fig. 1) in silicon is used, with a diameter of 300 mm and a thickness of 725 micrometers.

A sapphire receiver substrate 3 is also used with the same diameter and a thickness of 675 micrometers.

The substrate 1 is oxidized at the surface 10 (formation of 50 nanometers of oxide), is cleaned and prepared (for example by plasma activation), with view to its bonding on the substrate 3.

After oxidation and before bonding, it is subject to co-implantation of hydrogen and helium ions (arrows 2 of Fig. 1). The latter is performed by using the following doses: H^+: between 3 and 6.10^{16} at/cm² and He^+: of the order of 2.10^{16} at/cm². Preferentially, helium is implanted first.

The implantation energies are selected between a few keV and 200 keV, depending on the thickness of the layer 12 to be transferred.

This leads to the presence of an embrittlement area 11.

Once bonded, for example by molecular bonding, the thereby produced assembly, as it appears in Fig. 2, is subject to annealing for

detaching the thin layer 12, which is carried out under the following conditions:

- the structure is placed between two heating electrodes, the one positioned on the silicon substrate side being at a temperature above that of the one positioned on the sapphire substrate side;
- these temperatures are selected so that the whole of the volume of the silicon substrate is brought to 300°C, and the whole of the volume of the sapphire substrate is brought to 80°C.

The latter temperature is advantageous in order to minimize the stresses from the sapphire and for promoting development of "platelets" in the detachment plane.

In a particular example, the temperatures may be selected so as to place the donor substrate in a slightly compressive stress condition. This has the particular advantage of promoting formation of defects, precursors to fracture.

An alternative to the technique mentioned above consists of placing each of the substrates on a support brought to the adequate temperature, for example by circulating a liquid in this support. The adequate temperature may be less than room temperature or equal to room temperature. For example, the supporting substrate may be placed on a support which is temperature-controlled by circulation of a liquid, the temperature of which is less than or equal to room temperature.

Alternatively, application of a first temperature on the donor substrate and of a second temperature on the receiver substrate, may correspond to simple application of a temperature to the donor substrate while the receiver substrate is only subject to application of room temperature.

By repeating the preceding alternative, this may correspond to the case when only the support on which the donor substrate is placed is brought to an adequate temperature. In any case, the first and second temperatures lead to reducing the tensile stress condition of the donor material.

This piece of equipment may be a bonding machine having two tool-holders supporting the substrate, allowing them to be brought to

the adequate temperature, as mentioned above, and putting them into contact.

In this case, the annealing and fracture may take place *in situ* in the machine. Alternatively, the fracture may be caused *ex situ* by applying a mechanical force (for example by means of a blade applied sideways at the embrittled area).

Finally conventional steps for finishing the thereby formed SoS structure may be applied, such as steps for polishing, stabilization annealing of the bonding interface, sacrificial oxidation, etc.

CLAIMS

1. A method for manufacturing a heterostructure notably intended for applications in the field of electronics, photovoltaics, optics or optoelectronics, which comprises the following steps:

- implantation of atomic species inside a first so-called "donor" substrate (1), so as to form an embrittlement area (11) therein,
- assembly of a second so-called "receiver" substrate (3), on the donor substrate (1),
- detachment of the rear portion of said donor substrate (1) along the embrittlement area (11) so as to individualize a thin layer of interest (12) on the receiver substrate,

wherein said receiver substrate (3) has a larger thermal expansion coefficient than that of the donor substrate (1), and which applies so-called "detachment" annealing after said assembly and before said detachment, in order to facilitate the latter,

characterized by the fact that said detachment annealing comprises the simultaneous application:

- of a first temperature to the donor substrate (1);
- of a second temperature different from the first to the receiver substrate (3);

these first and second temperatures being selected to as to reduce the tensile stress condition of the donor substrate (1).

2. The method according to claim 1, characterized by the fact that it comprises a preliminary step which consists in forming or depositing an insulator layer on the donor substrate (1) so that there exists between them a so-called "binding" interface, and in that the assembling of the receiver substrate (3) on the donor substrate (1) is accomplished on the free surface of the insulator.

3. The method according to claim 1 or 2, characterized by the fact that the assembling of the receiver substrate (3) on the donor substrate (1) is achieved by molecular bonding.

4. The method according to any of the preceding claims, characterized by the fact that said detachment annealing is accompanied and/or continued by applying mechanical forces.

5. The method according to any of the preceding claims, characterized by the fact that application of the first and second temperatures is accomplished in such a way that the whole of the volume of each substrate (1; 3) has a homogenous temperature.

6. The method according to claim 5, characterized by the fact that said first and second temperatures are applied by placing said structure between two heating electrodes.

7. The method according to claim 5, characterized by the fact that the application of the first and second temperatures is accomplished by placing each substrate on an associated support brought to the corresponding temperature.

8. The method according to claim 7, characterized by the fact that a support associated with each substrate (1; 3) is used, which is an integral part of the bonding machine.

9. The method according to any of the preceding claims, characterized by the fact that said donor substrate (1) is in silicon, while the receiver substrate (3) is in sapphire, said first temperature being above the second.

10. The method according to any of the preceding claims, characterized by the fact that said first temperature is of the order of 300°C, while the second is of the order of 80°C.