METHOD FOR FABRICATING A STRAINED SEMICONDUCTOR-ON-INSULATOR SUBSTRATE

FIELD OF THE INVENTION

The present invention relates to a method for fabricating a strained semiconductor-on-insulator substrate, as well as such a substrate.

BACKGROUND OF THE INVENTION

For digital applications, in particular for technological nodes beyond the 22 nm node, materials with enhanced charge carrier mobility are sought.

Among these materials, FDSOI (acronym for fully depleted silicon-on-insulator) substrates feature a very thin (i.e. typically less than 50 nm thick) layer of silicon on a buried electrically insulating layer, the silicon layer potentially being used to form the channel of a CMOS transistor.

Strained silicon-on-insulator (sSOI) has been identified as a solution allowing the mobility of charge carriers in the silicon layer to be enhanced and good performance thereof has been demonstrated.

Various fabrication methods are known.

Document US 2014/0225160 discloses in particular a method allowing at least part of a strain present in a silicon-germanium layer located on the surface of a receiving substrate to be transferred to an initially relaxed silicon layer bonded to said receiving substrate via a dielectric layer that is intended to form the buried insulating layer of the SOI. This strain transfer occurs when a portion of said stack is cut by means of trenches that extend into the receiving substrate at least beyond the strained silicon-germanium layer. Thus, a relaxation of the compressive strain of the silicon-germanium layer is at least partially transmitted in the form of a tensile strain of the silicon layer.

Based on this principle, an sSOI substrate can be manufactured according to the following steps:

- a donor substrate 1 comprising a monocrystalline silicon layer 10 covered by a silicon oxide layer 11 is provided (cf. Figure 1A);
- ionic species are implanted into the donor substrate 1 so as to form a weakened zone 12 allowing a silicon layer 13 to be transferred to be defined (cf. Figure 1B);
- a receiving substrate 2 comprising a surface layer 20 of silicon-germanium under compressive strain is provided (cf. Figure 1C);
- the donor substrate 1 is bonded to the receiving substrate 2, the silicon oxide layer 11—which is intended to form the buried insulating layer of the sSOI substrate—and the strained silicon-germanium layer 20 being at the bonding interface (cf. Figure 1D);

the monocrystalline silicon layer 13 is transferred to the receiving substrate 2 by detaching the donor substrate along the weakened zone (cf. Figure 1E);

- trenches T are formed around a portion of the stack consisting of the strained silicon-germanium layer 20, the buried oxide layer 11 and the transferred semiconductor layer 13, said trenches extending into the receiver substrate 2 beyond the strained silicon-germanium layer 20 (cf. Figure 1F). Said cutting operation results in the at least partial relaxation of the silicon-germanium and the transmission of at least part of said strain to the transferred silicon layer in said portion, thus allowing the strained semiconductor-on-insulator substrate, denoted by sSOI, to be formed.

For applications beyond the 22 nm technological node, the thickness of the buried dielectric layer should be less than or equal to 25 nm.

For such a low thickness of the dielectric layer, the final defectivity of the sSOI substrate heavily depends on the bonding conditions, and in particular on the materials present at the bonding interface.

However, although surface preparation treatments that are conventionally used in the field of semiconductors are applied to the silicon-germanium layer, a substantial degree of defectivity of the sSOI substrate is still observed.

BRIEF DESCRIPTION OF THE INVENTION

Embodiments of the invention seek to provide a method for fabricating a strained semiconductor-on-insulator substrate that makes it possible to decrease the defectivity of said substrate linked to the conditions of bonding the donor substrate to the receiving layer.

According to an aspect of the invention, a method for fabricating a strained semiconductor-on-insulator substrate comprises:

(a) the provision of a donor substrate comprising a monocrystalline semiconductor layer;

(b) the provision of a receiving substrate comprising a surface layer of a strained monocrystalline semiconductor material;

(c) the bonding of the donor substrate to the receiving substrate, a dielectric layer being at the interface between the monocrystalline semi-conductor layer of the donor substrate and the surface layer of the receiving substrate;

(d) the transfer of the monocrystalline semiconductor layer from the donor substrate to the receiving substrate;

(e) the cutting of a portion from a stack formed from the transferred monocrystalline semiconductor layer, from the dielectric layer and from the strained semiconductor material layer, by forming trench isolations extending into said stack beyond the strained semiconductor material layer, said cutting operation resulting in the relaxation of the strain in the strained semiconductor material, and in the application of at least a part of said strain to the transferred monocrystalline semiconductor layer;

said method being characterized in that step (b) additionally comprises the formation, on the strained semiconductor material layer of the receiving substrate, of a dielectric bonding layer or of a bonding layer consisting of the same relaxed, or at least partially relaxed, monocrystalline material as the monocrystalline semiconductor layer of the donor substrate, and in that in step (c) said bonding layer is at the bonding interface between the donor substrate and the receiving substrate.

The present text is concerned with the strain in a plane parallel to the main surface of the layers in question.

The bonding layer formed on the receiving substrate allows materials providing optimum bonding quality in terms of final defectivity to be brought into contact at the bonding interface.

According to other advantageous features, taken alone or in combination as appropriate:

- according to one embodiment, the bonding layer is formed by deposition of a dielectric material on the strained semiconductor material layer of the receiving substrate;
- the donor substrate comprises a first dielectric layer on the monocrystalline semiconductor layer, the first dielectric layer and the bonding layer together forming a buried electrically insulating layer of the strained semiconductor-on-insulator substrate;
- the bonding layer comprises an oxide or a nitride of a semiconductor material;
- the thickness of the bonding layer is between 1 and 30 nm;
- according to another embodiment, the bonding layer is formed by epitaxy, on the strained semiconductor material layer, of the same semiconductor material as the monocrystalline semiconductor layer of the donor substrate;
- the thickness of said bonding layer is between 1 and 20 nm;
- the bonding layer and the monocrystalline semiconductor layer of the donor substrate are made of silicon;
- the strained semiconductor material layer is made of silicon-germanium;
- the strained semiconductor layer is formed by epitaxy on a silicon carrier substrate;
- upon completion of step (d), the thickness of the dielectric layer included between the transferred monocrystalline semiconductor layer and the strained semiconductor material layer is less than or equal to 50 nm, preferably less than or equal to 25 nm;
- step (a) comprises an operation of implanting ionic species into the donor substrate so as to form a weakened zone defining the monocrystalline semiconductor layer, and step (d) comprises the detachment of the donor substrate along said weakened zone.
- step (d) comprises an operation of thinning the donor substrate on the face opposite the bonding interface up to the transferred monocrystalline semiconductor layer;
- the method additionally comprises, before step (e), a step of thinning and/or smoothing the transferred monocrystalline semiconductor layer;

- the operation of cutting said portion of the stack is carried out by means of trench isolations extending into the receiving substrate beyond the strained semiconductor material layer.

Another aspect of the invention relates to a strained semiconductor-on-insulator substrate obtained by means of a method such as described above.

Said substrate comprises, in succession, a strained monocrystalline semiconductor layer, an electrically insulating layer, an at least partially relaxed layer of the same material as the strained semiconductor layer, a relaxed layer of a semiconductor material that differs from that of the strained semiconductor layer and a carrier substrate.

Advantageously, the thickness of the electrically insulating layer is less than or equal to 50 nm, preferably less than or equal to 25 nm, and the thickness of the at least partially relaxed layer of the same material as the strained semiconductor layer is between 1 and 20 nm.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention will emerge from the detailed description which follows, with reference to the appended drawings in which:

- Figures 1A to 1F schematically illustrate steps of a method for fabricating a strained silicon-on-insulator substrate leading to overly high defectivity;
- Figures 2A to 2G schematically illustrate steps of a method for fabricating a strained semiconductor-on-insulator substrate according to a first embodiment of the invention;
- Figures 3A to 3G schematically illustrate steps of a method for fabricating a strained semiconductor-on-insulator substrate according to a second embodiment of the invention;
- Figures 4A to 4G schematically illustrate steps of a method for fabricating a strained semiconductor-on-insulator substrate according to a third embodiment of the invention;

In order to facilitate the readability of the figures, the various layers are not shown to scale.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

A donor substrate is provided that comprises at least one monocrystalline semiconductor layer. The substrate may be a bulk semiconductor substrate or else a composite substrate, i.e. which consists of at least two layers of different materials including the monocrystalline semiconductor layer which is arranged on the surface of said substrate.

The material of the monocrystalline semiconductor layer may in particular be silicon, germanium or silicon-germanium.

At this stage in the method, said monocrystalline semiconductor layer is in the relaxed state.

According to one embodiment, the monocrystalline semiconductor layer is covered by a dielectric layer. Said dielectric layer may in particular be a layer of an oxide or of a nitride of a semiconductor material.

For example, if the monocrystalline layer is a silicon layer, the dielectric layer may be a silicon oxide (SiO_2) layer.

Said dielectric layer will form all or part of the buried insulating layer of the strained semiconductor-on-insulator substrate.

Alternatively, the monocrystalline semiconductor layer is not covered by such a dielectric layer and it is the free surface thereof that forms the surface of the donor substrate.

A receiving substrate that comprises a surface layer of a strained semiconductor material is also provided. Said layer may be formed by epitaxy on a carrier substrate having a lattice parameter that differs from that of the material of the strained layer.

The strain in this layer may be, depending on the materials used and on the nature of the strain to which it is desired to subject the semiconductor layer of the strained semiconductor-on-insulator substrate, compressive or tensile.

For example, the strained semiconductor material layer may be a silicon-germanium layer, formed by epitaxy on a silicon carrier substrate. The germanium content of said layer is typically of the order of 20% to 40%, although these values are not limiting, the choice thereof potentially being made according to the thickness of said layer. In this case, the strain in the silicon-germanium layer is compressive.

In order to form the strained semiconductor-on-insulator substrate, the monocrystalline semiconductor layer of the donor substrate should be transferred to the receiver substrate, this transfer comprising an operation of bonding the donor substrate to the receiver substrate, the monocrystalline semiconductor layer of the donor substrate and the strained semiconductor material layer being located on the bonding interface side.

A bonding layer is formed beforehand on the strained semiconductor material layer of the receiving substrate, which bonding layer allows materials providing optimum bonding quality in terms of final defectivity to be brought into contact at the bonding interface.

According to one embodiment, said bonding layer is a dielectric layer.

In the case in which the monocrystalline semiconductor layer of the donor substrate is also covered by a dielectric layer (referred to as the first dielectric layer), the bonding interface will consist of said first dielectric layer and of the bonding layer (referred to as the

second dielectric layer). Said first and second dielectric layers thus together form the buried insulating layer of the final sSOI.

In the case in which the monocrystalline semiconductor layer of the donor substrate is not covered by a dielectric layer, the bonding interface will consist of said monocrystalline semiconductor layer and of the bonding layer. It is then the bonding layer alone that forms the buried insulating layer of the final sSOI.

Advantageously, the bonding layer comprises an oxide or a nitride of a semiconductor material.

Said bonding layer is formed by deposition on the strained semiconductor material layer of the receiving substrate. Any suitable deposition technique may be used. In a non-limiting manner, the vapour phase deposition variants known by the acronyms PE-CVD or PE-ALD may thus be cited.

The thickness of the bonding layer is chosen according to whether a first dielectric layer is present on the monocrystalline semiconductor layer of the donor substrate so as to obtain the desired thickness of the buried insulating layer, which is generally less than or equal to 50 nm, preferably less than or equal to 25 nm.

Advantageously, said thickness is also chosen while taking the thermal budget applied to the receiving substrate during the deposition of said layer into consideration, in order to limit the relaxation of the strain in the strained semiconductor material layer caused by this thermal budget. Thus, for example, if the strained semiconductor material layer is a silicon-germanium layer, the germanium is liable to diffuse out of said layer under the effect of a high thermal budget, thereby decreasing the strain in said layer. The thermal budget should therefore be limited in order to avoid a substantial decrease in the strain and thus retain the strain which will be imparted to the monocrystalline semiconductor layer of the sSOI substrate.

The thickness of the bonding layer is typically between 1 and 30 nm.

According to another embodiment, the bonding layer consists of the same monocrystalline material, in the relaxed or partially relaxed state, as the monocrystalline semiconductor layer of the donor substrate.

In this case, the monocrystalline semiconductor layer is covered by a dielectric layer that will form the buried insulating layer of the sSOI substrate.

The bonding layer is formed by epitaxy, on the strained semiconductor material layer, of the same semiconductor material as the monocrystalline semiconductor layer of the donor substrate.

The thickness of the bonding layer is advantageously chosen so that it is thin enough to offer the desired level of protection between the SiGe layer and the bonding interface, while taking, as in the preceding embodiment, the thermal budget applied to the receiving substrate during the deposition of said layer into consideration, in order to limit

the relaxation of the strain in the strained semiconductor material layer caused by this thermal budget. Said thickness also takes account of the removal of material caused by the pre-bonding surface preparation treatment, which may include wet or dry etching.

By way of example, the thickness of such a silicon bonding layer is between 1 and 20 nm.

In the two embodiments proposed by the invention, the bonding interface makes either contact between two dielectric layers or contact between a dielectric layer and a layer of the same monocrystalline material, in the relaxed or partially relaxed state, as the monocrystalline semiconductor layer of the donor substrate. These two situations correspond to the bonding configurations that provide minimum final defectivity.

After bonding the donor substrate to the receiving substrate, the monocrystalline semiconductor layer is transferred to the receiving substrate.

According to one embodiment, said transfer involves the Smart Cut™ method. In a manner known per se, this transfer comprises:

- prior to the bonding operation, ionic species are implanted into the donor substrate so as to form a weakened zone allowing the monocrystalline semiconductor layer to be transferred to be defined;
- after the bonding operation, the donor substrate is detached along the weakened zone.

The conditions of implementation of such a method are known to those skilled in the art and as such will not be described in detail in the present text.

According to another embodiment, the transfer involves thinning the donor substrate on its back face, i.e. the face opposite the bonding interface. As is well known, such a thinning operation may involve one or more steps of dry or wet etching and/or polishing, especially chemical-mechanical polishing, etc.

The invention is not limited with respect to the transfer technique used.

After the transfer itself, the transferred semiconductor layer can undergo a finishing treatment allowing residual defects linked to the transfer process to be removed and the transferred monocrystalline semiconductor layer to be smoothed and thinned to the desired thickness. This type of treatment is known to those skilled in the art and as such will not be described in detail here. Typically, the final thickness of the monocrystalline semiconductor layer of the sSOI substrate is between 5 and 50 nm.

Lastly, a portion of the stack consisting of the transferred semiconductor layer, of the buried insulating layer (which is formed, as disclosed above, from the bonding layer and/or from a dielectric layer of the donor substrate) and of the strained semiconductor material layer is cut in order to form the sSOI substrate.

Said cutting operation is advantageously carried out by etching trench isolations around said portion. In order to allow the relaxation of the strained semiconductor material

layer to be optimally transmitted to the transferred monocrystalline semiconductor layer, said trenches should extend into the thickness of the receiving substrate beyond said strained semiconductor material layer. The technique for fabricating said trenches is well known to those skilled in the art and as such does not need to be described in detail in the present text.

The resulting structure comprises, from its base to its surface, the carrier substrate, the initially strained semiconductor material layer, which is now in the relaxed state, the buried insulating layer and the transferred semiconductor monocrystalline layer, which is now in the strained state. If the bonding layer is made of a dielectric material, it forms at least part (or even all) of the buried insulating layer. If the bonding layer is made of the same material, in the relaxed or partially relaxed state, as the transferred semiconductor layer, said bonding layer is intercalated between the initially strained semiconductor material layer, which is now in the relaxed state, and the buried insulating layer.

With respect to an sSOI substrate obtained via the method illustrated in Figures 1A to 1F with the same cleaning, donor substrate preparation and bonding conditions, an sSOI substrate obtained according to the method described above exhibits, upon visual inspection, a much lower degree of defectivity, which results in particular in a substantial decrease in the number of holes corresponding to non-transferred zones of the monocrystalline semiconductor layer.

Figures 2A to 2G schematically illustrate steps of the fabrication of a strained semiconductor-on-insulator substrate according to one form of execution of the invention.

Figure 2A illustrates the provision of the donor substrate 1 which, in this illustration, is a bulk substrate of a monocrystalline semiconductor material. Alternatively, said substrate could be a composite and comprise, on one of its faces, a monocrystalline semiconductor layer.

Furthermore, in the embodiment illustrated in Figure 2A, the donor substrate 1 is covered by a dielectric layer 11.

Figure 2B illustrates the implementation of an implantation of ionic species into the donor substrate 1 so as to form a weakened zone 12 defining a defining a monocrystalline semiconductor layer 13 to be transferred by means of the Smart Cut™ method. This step is optional, the transfer potentially being carried out by means of a method other than the Smart Cut™ method, for example by thinning the donor substrate on its back face.

Figure 2C illustrates the provision of the receiving substrate 2 which comprises a surface layer 20 of a strained semiconductor material on a carrier substrate 21.

Figure 2D illustrates the formation of the bonding layer 22 which, in this case, consists of a dielectric material deposited on the strained semiconductor material layer 20.

Figure 2E illustrates the bonding of the donor substrate to the receiving substrate, the dielectric layers 11 and 22 together forming the buried insulating layer (referred to as a

single layer 30 in the following figures) of the final strained semiconductor-on-insulator substrate. The bonding interface is denoted by the reference I.

Figure 2F illustrates the structure obtained after detaching the donor substrate along the weakened zone and, if applicable, after the transferred monocrystalline semiconductor layer 13 has undergone the finishing treatment. Alternatively, if the Smart Cut™ method is not used, said structure may be obtained by thinning the back face of the donor substrate up to the layer 13 and smoothing the surface of said layer.

Figure 2G illustrates the sSOI substrate obtained after cutting trenches T around the stack of layers 13, 30, 20 up to within the thickness of the carrier substrate 21.

Figures 3A to 3G schematically illustrate steps of the fabrication of a strained semiconductor-on-insulator substrate according to another form of execution of the invention.

The elements denoted by the same references as in Figures 2A to 2G are of the same nature and as such are not described again.

The steps illustrated in Figures 3A to 3C are similar to those of Figures 2A to 2C.

Figure 3D illustrates the formation of a bonding layer 23 which, in this case, consists of the same material as that of the layer 13, in the relaxed or partially relaxed state, by epitaxy on the strained semiconductor material layer 20.

The steps illustrated in Figures 3E to 3G are similar to those of Figures 2E to 2G, except in that the buried insulating layer of the sSOI substrate consists of the single dielectric layer 11 of the donor substrate, and that the bonding layer 23 is intercalated between the strained semiconductor material layer 20 and said buried insulating layer.

Figures 4A to 4G schematically illustrate steps of the fabrication of a strained semiconductor-on-insulator substrate according to another form of execution of the invention.

The elements denoted by the same references as in Figures 2A to 2G or 3A to 3G are of the same nature and as such are not described again.

The steps illustrated in Figures 4A to 4C are similar to those of Figures 2A to 2C, except in that the donor substrate 1 is not covered by a dielectric layer. Stated otherwise, it is the semiconductor surface of the layer 13 to be transferred that is exposed.

Figure 4D illustrates the formation of a bonding layer 22 which, in this case, consists of a dielectric material deposited on the strained semiconductor material layer 20.

The steps illustrate in Figures 4E to 4G are similar to those of Figures 2E to 2G, except in that the buried insulating layer of the sSOI substrate consists of the single bonding layer 22.

Lastly, it goes without saying that the examples given above are only particular illustrations that are in no way limiting with respect to the fields of application of the invention.

REFERENCES

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CLAIMS

1. Method for fabricating a strained semiconductor-on-insulator substrate, comprising:

(a) the provision of a donor substrate (1) comprising a monocrystalline semiconductor layer (13);

(b) the provision of a receiving substrate (2) comprising a surface layer (20) of a strained monocrystalline semiconductor material;

(c) the bonding of the donor substrate (1) to the receiving substrate (2), a dielectric layer (11, 22) being at the interface between the monocrystalline semi-conductor layer (13) of the donor substrate and the surface layer (20) of the receiving substrate;

(d) the transfer of the monocrystalline semiconductor layer (13) from the donor substrate (1) to the receiving substrate (2);

(e) the cutting of a portion from a stack formed from the transferred monocrystalline semiconductor layer (13), from the dielectric layer (11, 22) and from the strained semiconductor material layer (20), by forming trench isolations (T) extending into said stack beyond the strained semiconductor material layer (20), said cutting operation resulting in the relaxation of the strain in the strained semiconductor material, and in the application of at least a part of said strain to the transferred monocrystalline semiconductor layer;

said method being characterized in that step (b) additionally comprises the formation, on the strained semiconductor material layer (20) of the receiving substrate (2), of a dielectric bonding layer (22) or of a bonding layer consisting of the same relaxed, or at least partially relaxed, monocrystalline material (23) as the monocrystalline semiconductor layer (13) of the donor substrate (1), and in that in step (c) said bonding layer (22, 23) is at the bonding interface between the donor substrate and the receiving substrate.

2. Method according to Claim 1, in which said bonding layer (22) is formed by deposition of a dielectric material on the strained semiconductor material layer (20) of the receiving substrate.

3. Method according to Claim 2, in which the donor substrate (1) comprises a first dielectric layer (11) on the monocrystalline semiconductor layer, the first dielectric layer (11) and the bonding layer (22) together forming a buried electrically insulating layer (30) of the strained semiconductor-on-insulator substrate.

4. Method according to either of Claims 2 and 3, in which the bonding layer (22) comprises an oxide or a nitride of a semiconductor material.

5. Method according to one of Claims 2 to 4, in which the thickness of the bonding layer (22) is between 1 and 30 nm.

6. Method according to Claim 1, in which the bonding layer (23) is formed by epitaxy, on the strained semiconductor material layer (20), of the same semiconductor material as the monocrystalline semiconductor layer (13) of the donor substrate (1).

7. Method according to Claim 6, in which the thickness of the bonding layer (23) is between 1 and 20 nm.

8. Method according to either of Claims 6 and 7, in which the bonding layer (23) and the monocrystalline semiconductor layer (13) of the donor substrate are made of silicon.

9. Method according to one of Claims 1 to 8, in which the strained semiconductor material layer (20) is made of silicon-germanium.

10. Method according to Claim 9, in which said strained semiconductor layer (20) is formed by epitaxy on a silicon carrier substrate (21).

11. Method according to one of Claims 1 to 10, in which, upon completion of step (d), the thickness of the dielectric layer (11, 22, 30) included between the transferred monocrystalline semiconductor layer (13) and the strained semiconductor material layer (20) is less than or equal to 50 nm, preferably less than or equal to 25 nm.

12. Method according to one of Claims 1 to 11, in which step (a) comprises an operation of implanting ionic species into the donor substrate (1) so as to form a weakened zone (12) defining the monocrystalline semiconductor layer (13), and step (d) comprises the detachment of the donor substrate (1) along said weakened zone (12).

13. Method according to one of Claims 1 to 11, in which step (d) comprises an operation of thinning the donor substrate (1) on the face opposite the bonding interface (I) up to the transferred monocrystalline semiconductor layer (13).

14. Method according to one of Claims 1 to 13, additionally comprising, before step (e), a step of thinning and/or smoothing the transferred monocrystalline semiconductor layer (13).

15. Method according to one of Claims 1 to 14, in which the operation of cutting said portion of the stack is carried out by means of trench isolations (T) extending into the receiving substrate (2) beyond the strained semiconductor material layer (20).

16. Strained semiconductor-on-insulator substrate, comprising successively: a strained monocrystalline semiconductor layer (13), an electrically insulating layer (11), an at least partially relaxed layer (23) of the same material as the strained semiconductor layer (13), a relaxed layer (20) of a semiconductor material that differs from that of the strained semiconductor layer (13) and a carrier substrate (21).

17. Substrate according to Claim 16, in which the thickness of the electrically insulating layer (11) is less than or equal to 50 nm, preferably less than or equal to 25 nm, and the thickness of the at least partially relaxed layer (23) of the same material as the strained semiconductor layer is between 1 and 20 nm.