PROCESS FOR TRANSFER OF A THIN LAYER FORMED IN A SUBSTRATE WITH VACANCY CLUSTERS

The invention relates to a process for making a substrate by transfer of a thin layer of semiconducting material from a donor substrate to a support substrate.

One field of application of the invention is for processes for making semiconductor on insulator (SeOI) structures, for example silicon on insulator (SOI) structures, these SeOI structures acting as substrates for electronics, optics and optoelectronics.

SeOI structures thus comprise an insulating layer inserted between a thin layer made of a semiconducting material and a support substrate.

SMARTCUT® type processes are an example of a process of this type. These processes correspond to a preferred embodiment of the invention.

Further details about the SMARTCUT® process are given in the "Silicon-On-Insulator Technology: Materials to VLSI, 2nd Edition" document by Jean-Pierre Colinge published by "Kluwer Academic Publishers", p. 50 and 51.

Production of an SeOI structure using the SMARTCUT® process and particularly an SeOI structure in which the thin layer is particularly thin (typically less than 400 nm) requires the use of an initial donor

substrate without any growth defects in the form of vacancy clusters (known as Crystal Originated Particles or COPs).

The presence of these vacancy clusters in the volume of the donor substrate may generate defects for which the size is larger than the thickness of the thin layer of the final SeOI structure.

These said through defects are said to be fatal defects; a component formed on one of these defects will not work. The presence of these through defects is therefore a parameter that controls the quality of components that will be created on the final structure. Therefore, it is essential to minimise the presence of these through defects.

Obviously, it will be understood that the problem of through defects is particularly important if the thickness of the thin layer is thin.

One solution for limiting the number of through defects in an SeOI substrate and that has been frequently used in the past is to use an initial substrate with a very high crystallographic quality, having a low density of COPs.

Initial substrates are typically formed by cutting into an ingot obtained by the CZ process (Czochralski pulling).

Control over the pulling speed and the ingot cooling rate provides a means of reducing the quantity of vacancy cluster type defects. Thus, an initial substrate with almost no COPs is typically formed by cutting an ingot obtained by the CZ (Czochralski pulling) process using very specific pulling conditions

and particularly very slow pulling (pulling also designated by the name "Very Slow Pull" to obtain what those skilled in the art call a Near Perfect Crystal due to the very low number of defects).

Substrates formed by cutting in an ingot obtained by simpler and / or faster pulling processes have comparatively more vacancy clusters and are therefore considered to be incompatible with the constraints imposed in target application fields (such as optics, electronics or optoelectronics).

For example, a substrate formed by cutting a Near Perfect Crystal obtained by a "Very Slow Pull" type pulling at a rate of less than 0.5 mm/min will typically have a density of COPs (larger than 0.1 μm) between 0.045 and 0.075 COPs/cm^2 (equivalent to 30 to 50 COPs larger than 0.1 μm in a 300 mm diameter wafer with a surface area of 660 cm^2 allowing for a 5 mm exclusion area around the wafer).

Comparatively, a substrate obtained using standard pulling at a rate 1.2 to 1.5 times faster than the "Very Slow Pull" type pulling, will have a density of COPs (larger than 0.1 μm) between 1.5 and 4.5 COPs/cm^2 (equivalent to 1000 to 3000 COPs larger than 0.1 μm in a 300 mm diameter wafer).

It will be noted that the ingot cooling rate during pulling is another factor that will influence its crystallographic quality. Information about this subject is given in chapter 1.6 "Si MELT GROWTH: GROWN-IN DEFECTS AND SIMULATION OF THEIR FORMATION" by W. von Ammon and E. Domberger, pages 39 - 51 in the "Properties of Crystalline Silicon" document published

by Robert Hull in INSPEC publications (January 1998) that demonstrates that a high cooling rate (pulling designated as "Fast Cool") is accompanied by an increase in the density of defects. Therefore a substrate obtained by cutting an ingot obtained by "Fast Cool" type pulling is also incompatible with imposed constraints in the application fields of the invention.

The production efficiency for a quality substrate (Near Perfect Crystal with almost no COPs by means of a CZ "Very Slow Pull" type pulling) is significantly lower than the production efficiency of substrates using simpler and / or faster pulling processes. Therefore the production of a near perfect substrate by "Very Slow Pull" type pulling is particularly expensive; its cost is thus typically 30% greater than the cost of substrates obtained by standard CZ pulling.

It will be noted that it has also been proposed to use a previously heat treated standard substrate to reduce the quantity of COPs, as an initial substrate in a process for making an SOI structure. Further information about this subject is given for example in the article "A NOVEL METHOD FOR ACHIEVING VERY LOW COPS IN CZ WAFERS" by J. L. Vasat and T. Torack, published in the March 2003 issue of the Solid State Technology journal.

However, the use of such a previous heat treatment is not satisfactory. This treatment modifies the surface properties of the initial substrate (and in particular increases its surface roughness) such that problems can occur during bonding of the initial

substrate to a support substrate (and particularly degradation of the bonding quality). Furthermore, this previous heat treatment can generate "slip line" type defects or oxygen precipitates that could compromise recycling of the initial substrate that is usually used in a SMARTCUT® type process.

One purpose of the invention is to reduce the cost price of substrates made by transfer of a thin layer of semiconducting material from a donor substrate to a support substrate, and particularly the cost price of SeOI substrates.

More specifically, the invention is aimed to enable the use of initial substrates formed by cutting an ingot obtained by CZ pulling which is more cost effective than the "Very Slow Pull" type pulling to obtain a near perfect crystal, in a SMARTCUT® type transfer process, while maintaining a crystalline quality of the thin layer compatible with the envisaged applications, without encountering any bonding or recycling type problems caused by use .of the previous heat treatment technique mentioned above.

To achieve this, according to a first aspect, there is provided a process for making a semiconductor on insulator substrate comprising an insulating layer inserted between a thin layer of semiconducting material and a support substrate, the thin layer resulting from the transfer onto the support substrate of a part of a donor substrate with vacancy clusters being present with the support substrate at a first density, characterised in that it comprises:

- before transfer of said part from the donor substrate onto the support substrate, a forming

step of the insulating layer adapted not to increase the size of the vacancy clusters present in said part of the donor substrate at said first density,

- and after the transfer, a curing step of the vacancy clusters present in the part of the donor substrate transferred onto the support substrate to reduce the first density to a second density.

The following gives a list of some preferred but limitative aspects of this process:

- the forming step of the insulating layer is performed by thermal oxidation of the support substrate;
- the forming step of the insulating layer is performed by deposition of an oxide layer on the donor substrate and / or the support substrate;
- the curing step is performed immediately after transfer;
- the curing step is performed by applying a thermal annealing to the structure obtained after transfer;
- the thermal annealing is carried out under a non-oxidising atmosphere;
- the thermal annealing is carried out under an atmosphere containing pure hydrogen, pure argon or a hydrogen / argon mix;
- the thermal annealing is a rapid thermal processing (RTP);
- the thermal annealing is done in a furnace;

- the thermal annealing is a smoothing annealing performed under an atmosphere containing hydrogen and hydrochloric acid;
- the donor substrate is a substrate formed by cutting an ingot from the said semiconducting material obtained by pulling creating vacancy clusters with an average size less than the size of clusters present in a near perfect substrate formed by cutting an ingot obtained by slow pulling;
- the donor substrate is formed by cutting an ingot obtained by CZ pulling such that the density of clusters of created vacancies larger than 0.14 μm is less than 0.01/cm^2;
- it comprises a preliminary step to prepare the donor substrate including the following operations;
  - making an ingot of the said semiconducting material by pulling creating vacancy clusters with an average size less than the size of clusters present in a near perfect substrate formed by cutting an ingot obtained by slow pulling;
  - and cutting the donor substrate in this ingot;
- the donor substrate is formed by cutting an ingot obtained by CZ pulling such that the density of created clusters of vacancies smaller than 0.2 μm is greater than 1.5/cm^2;
- the donor substrate is formed by cutting an ingot obtained by CZ pulling such that the

density of created clusters of vacancies smaller than 0.12 μm is greater than $3/cm^2$;

- the donor substrate is formed by cutting an ingot obtained by a CZ process by pulling at a rate at least 1.2 times greater than the rate of the said slow pulling to obtain a near perfect crystal;
- the donor substrate is formed by cutting an ingot subjected to fast cooling;
- the donor substrate is a substrate formed by cutting an ingot subjected to nitrogen doping;
- it comprises a step consisting of creating a weakness zone within the thickness of the donor substrate without the said donor substrate having been previously submitted to a cleaning treatment;
- before the step to create a weakness zone, it includes a step consisting of depositing an oxide layer on the donor substrate surface to form a protection layer, the said protection layer possibly being removed once the weakness zone has been created;
- the donor substrate is made of silicon;
- the support substrate is obtained in the same way as the donor substrate.

According to another aspect, there is provided a semiconductor on insulator substrate comprising an insulating layer inserted between a thin layer of semiconducting material and a support substrate, obtained by the process disclosed herein, starting from a donor substrate with a density of vacancy clusters equal to approximately $3/cm^2$, characterised in that the thin layer has a density of vacancy clusters less than or equal to approximately $0.075/cm^2$.

According to one embodiment, there is provided a semiconductor on insulator substrate including an insulating layer inserted between a thin layer of semiconducting material and a support substrate obtained using the process disclosed herein, and particularly an SeOI

substrate obtained from a donor substrate with a density of vacancy clusters equal to approximately $3/cm^2$, characterised in that the thin layer finally comprises a density of vacancy clusters equal to or less than approximately $0.075/cm^2$.

According to another aspect, the invention relates to a process for making a substrate comprising a thin layer of semiconducting material and a support substrate, the thin layer resulting from the transfer onto the support substrate of a part of a donor substrate, vacancy clusters being present with the support substrate at a first density, characterised in that it comprises:

- after transfer of said part of the donor substrate onto the support substrate, a curing step of the vacancy clusters present in the part of the donor substrate transferred onto the support substrate to reduce the first density to a second density,
- and before said curing step, one or several steps adapted so as not to increase the size of the vacancy clusters present in said part of the donor substrate at said first density.

According to yet another aspect, there is provided a process for recycling a substrate with vacancy clusters and having been used as a donor substrate from which a thin layer was taken and transferred onto a support substrate, characterised in that it consists in one or several steps adapted so as not to increase the size of the vacancy clusters present in the said substrate.

Other aspects, purposes and advantages of this invention will become clear after reading the following detailed description of preferred embodiments of the invention, given as non-limitative examples and with reference to the attached drawings, in which:

- Figure 1 shows the variation of the size and density of COPs as a function of the pulling rate of an ingot;
- Figure 2 shows curing of COPs during implementation of a possible embodiment of the process according to the invention.

The invention relates to a process for making a substrate comprising a thin layer of semiconducting material and a support substrate, the thin layer resulting from the transfer of a part of a donor substrate with vacancy clusters at a first density.

One preferred embodiment of the invention relates particularly to a SMARTCUT® type transfer process, for which the main steps are mentioned below.

A donor substrate made of a semiconducting material from which the thin layer is formed is exposed to implantation of species to create a weakness zone within the thickness of the donor substrate. The face of the donor substrate in which the implantation was made is then brought into intimate contact with the support substrate. The donor substrate is then detached at the level of the weakness zone, part of the donor substrate thus being transferred onto the support substrate to form the thin layer on the support substrate.

When making an SeOI structure, an insulating layer is inserted between the thin layer and the support substrate.

In the context of the invention, the donor substrate is not necessarily formed by cutting an ingot with a near perfect crystal quality ("Near Perfect Crystal") obtained by "Very Slow Pull" type CZ pulling.

On the contrary, in the context of one advantageous embodiment of the process according to the invention for transferring a thin layer from a donor substrate to a support substrate, the donor substrate is formed by cutting an ingot of semiconducting material obtained by pulling creating vacancy clusters with an average size less than the average size of clusters present in a near perfect substrate formed by cutting an ingot obtained by a slow pulling.

According to one possible embodiment, the process according to the invention comprises a prior step for preparation of the donor substrate including an operation to make an ingot of semiconducting material by pulling creating vacancy clusters with an average size less than the average size of clusters present in a near perfect crystal obtained by slow pulling, and a step to cut out the donor substrate in this ingot.

The pulling mode mentioned above has the advantage that it is not very expensive compared with the "Very Slow Pull" type pulling.

For example, this type of pulling mode includes a fast CZ pulling or fast cooling to obtain a crystal commonly called a "Low Defect Crystal" or a crystal called a "Standard Crystal".

According to one advantageous embodiment of the process according to the invention, nitrogen doping can be performed when pulling the ingot from which the donor substrate is obtained. This type of nitrogen doping can facilitate the curing step (which will be described in detail later) so as to remove COPs from the transferred thin layer. For example, information about this subject is given in the article "GROWN-IN DEFECTS IN NITROGEN-DOPED CZROCHRALSKI SILICON" by X. YU, D. YANG, X.MA, J.YANG, L.LI and D.QUE published in July 2002 volume 92, number 1 of the "Journal of Applied Physics" journal, in which it describes that nitrogen doping of the ingot provides a means of generating smaller COPs (admittedly with a greater density), more susceptible to heat treatment.

Preferably, the nitrogen doping carried out during pulling of the ingot is adapted to introduce between 10^{14} and 5×10^{15} atoms of nitrogen/cm^3.

According to one advantageous embodiment of the invention, the support substrate is also prepared in the manner described above for the donor substrate, particularly by cutting an ingot formed by standard CZ pulling. The support substrate may also be subjected to nitrogen doping.

With reference to Figure 1, the Figure shows the variation in the size of COPs and the variation of density of COPs as a function of the pulling rate of an ingot of semiconducting material according to the CZ process.

Data about the number of COPs and their size presented in this Figure were obtained using the

Surfscan SP1 tool made by the KLA-Tencor Company for laser inspection of wafers, and particularly for counting COPs larger than 0.1 μm within a thickness of up to 5000 Angstroms under the surface of a 300 mm diameter wafer.

As is clear in Figure 1, the density of COPs increases with the pulling rate, while their size reduces with the pulling rate.

Thus, a substrate obtained with a very slow pulling rate of less than 0.5 mm/min has a density of COPs with a size between 0.1 μm and 0.3 μm approximately between 0.045 and 0.075 COPs/cm² (equivalent to 30 to 50 COPs with a size between 0.1 μm and 0.3 μm for a 300 mm diameter wafer).

This is the substrate with a near perfect crystallographic quality (Near Perfect Crystal) that is conventionally used to act as a donor substrate in a SMARTCUT® type process.

The density of COPs with a size between 0.1 μm and 0.3 μm in a substrate obtained by a "Slow Pull" type pulling speed 1 to 1.2 times greater than the "Very Slow pull" type pulling speed, is approximately between 0.75 and 1.5 COPs/cm² (equivalent to 500 to 1000 COPs with a size between 0.1 μm and 0.3 μm for a 300 mm diameter wafer).

The density of COPs with a size between 0.1 μm and 0.2 μm in a substrate obtained by a "Standard" pulling speed 1 to 1.2 times greater than the "Very Slow Pull" type pulling speed, is approximately between 1.5 and 4.5 COPs/cm² (equivalent to 1000 to 3000 COPs with a

size between 0.1 μm and 0.2 μm for a 300 mm diameter wafer).

Finally, the density of COPs with a size between 0.1 μm and 0.12 μm in a substrate obtained by a "Fast Pull" type pulling speed 1.5 to 2 times greater than the "Very Slow Pull" type pulling speed, is significantly greater than 3 COPs/cm² (equivalent to more than 2000 COPs with a size between 0.1 μm and 0.12 μm for a 300 mm diameter wafer).

Thus diagrammatically, a substrate cut out in an ingot obtained by standard or fast pulling has a high density of small COPs, while a substrate cut out in an ingot obtained by a slow pulling or a very slow pulling has a low density of large COPs. Thus, controlling the pulling speed provides a means of controlling the size and density of COPs.

In the same way as the control over the pulling speed, control over the ingot cooling rate provides a means of controlling the size and density of COPs. Thus, and as described in the document "Si MELT GROWTH: GROWN-IN DEFECTS AND SIMULATION OF THEIR FORMATION" already mentioned, fast cooling of an ingot reduces the size of defects but increases the density of the defects. Typically, fast cooling relates to cooling of the ingot during which the cooling time between 1100 and 800°C is reduced.

In the remainder of the description, we will use an example of a pulling creating vacancy clusters with an average size of less than the size of clusters present in a near perfect crystal (for example like that obtained with a "Fast Pull" type pulling). It will

be understood that the invention is not limited to this pulling mode, but can be extended to include any pulling mode, and advantageously to any pulling mode resulting in a substrate with an important number of COPs, but that is more economic than pulling to obtain a near prefect crystal substrate.

Thus, preparation of the support substrate by a CZ "Fast Pull" type pulling, which is significantly less expensive than a "Very Slow Pull" type pulling, provides an initial substrate with a high density of small COPs.

When the donor substrate is made by a fast pulling type CZ process (in opposition to the very slow pulling), and provided that the said donor substrate has not been subjected to a step that could increase the size of the COPs before transfer of the thin layer, the thin layer will not have any COPs that could generate through defects immediately after transfer onto the support substrate.

Due to fast pulling type, the donor substrate will only have small COPs (admittedly with a large density) that are not likely to pass through the entire thickness of the transferred thin layer.

However, some operations conventionally performed during a SMARTCUT® type transfer process could increase the size of COPs, thus causing the formation of through defects. For example oxidation, basic cleaning, polishing act on COPs and increase their size, particularly by etching of walls of the COPs in all directions.

When the SMARTCUT® process is used conventionally to make an SeOI type substrate, the donor substrate is typically subjected to thermal oxidation before being exposed to implantation of species to form the insulating layer inserted after transfer between the thin layer and the support substrate (this layer is usually referred to as the buried oxide layer).

The donor substrate oxidation step consumes material on the surface of the donor substrate, but also on the walls of COPs. The size of COPs is then increased, by the same order of magnitude as the thickness of oxide produced.

Moreover, in its material consumption, the effect of the thermal oxidation is to integrate volume COPs that are then transferred to the surface.

Thus, for a conventional embodiment of an SeOI substrate, the size of COPs could increase due to the thermal oxidation before transfer of the donor substrate, thus causing through defects after the transfer.

On the other hand, as has already been mentioned, due to the fast pulling that only generates small COPs (or more precisely such that the generated density of COPs larger than about 0.14 μm is less than 0.01/cm^2, which is equivalent to only a few COPs larger than 0.14 μm for a 300 mm wafer), in the lack of oxidation of the donor substrate before transfer (or more generally the use of any operation that could increase the size of COPs before the transfer), the COPs will usually not be large enough to form a through defect immediately after the transfer.

In the context of making an SeOI substrate according to the invention, and in order to avoid the formation of through defects, the buried insulating layer is not formed conventionally as described above by submitting the donor substrate to thermal oxidation.

Thus, before the transfer, the process according to the invention includes a step for formation of the insulating layer adapted so as to not increase the size of vacancy clusters present in the said thin layer.

In other words, the donor substrate has vacancy clusters at a first density and the step for formation of the insulating layer carried out before transfer of a part of the donor substrate onto the support substrate for forming the thin layer thereto is adapted so as not to increase the size of vacancy clusters present in the part of the donor substrate at said first density.

According to a first possible embodiment, the buried insulating layer is formed by submitting the support substrate rather than the donor substrate to a thermal oxidation (conventionally known in itself).

According to a second possible embodiment, the insulating layer is formed by deposition of an oxide layer on the donor substrate and / or on the support substrate.

For example, this type of deposition could be made using the Low Pressure Chemical Vapor Deposition (LPCVD) technique, for example at low temperature and under an atmosphere containing the TEOS (tetraethylorthosilicate $Si(OC_2H_5)_4$) precursor, or at

high temperature (High Temperature Oxide HTO) under an atmosphere containing silane and oxygen.

This type of deposition could also be made using the Plasma Enhanced Chemical Vapor Deposition (PECVD) technique, that can be used at a lower temperature than the LPCVD technique.

Now returning to the general description of the SMARTCUT® type transfer process according to the preferred embodiment of the invention, the support substrate is exposed to implantation of species adapted to create a weakness zone within its volume.

Note that in the case in which an oxide layer is deposited on the donor substrate to form the insulating layer of the final structure, this implantation of species is made through the said oxide layer deposited on the donor substrate.

Furthermore, this type of oxide layer deposited on the surface of the donor substrate could act as a protection layer to protect the surface of the donor substrate on which the implantation is made.

According to one possible embodiment, such an oxide layer is thus deposited on the donor substrate before implantation to act as a protection layer, and is then withdrawn after implantation before putting the donor and the support substrates into contact (in this case, the buried insulating layer may then for example be formed by oxidation of the support substrate, or by deposition of a new layer of oxide on the donor substrate).

Preferably, the donor substrate is not subjected to a cleaning step before implantation. As we have

already seen (and in the same way as for a thermal oxidation step of a donor substrate formed by fast pulling, this type of cleaning could increase the size of COPs and thus generate through defects.

As a variant to the possible embodiment of the invention described above, other implantation techniques (for example like that presented in the PCT patent application filed by this applicant on 21/09/2004 under number IB2002003300 and not yet published, co-implantation of several species, implantation by plasma) and / or other thin layer transfer techniques may be used.

Furthermore, the quasi-absence of large COPs (typically larger than about 0.14 μm) provides a means of transferring defect free layers that are thinner than those that can traditionally be transferred (when the donor substrate has large defects). The presence of "through" defects in the thin layer, in other words holes reaching the buried oxide layer, is directly related to the size of COPs in the donor substrate.

Thus, in the context of this invention, implantation parameters may be adjusted so as to transfer layers with a thickness of about 0.15 μm or more.

Returning to the description of a possible embodiment of the invention, the donor and support substrates are then brought into intimate contact, and the donor substrate is then detached at the level of the weakness zone. Part of the donor substrate is then transferred onto the support substrate to form the thin layer on the support substrate.

Bonding can be facilitated by applying a plasma activation treatment to either one or both the faces of the substrates brought into contact. This is particularly advantageous if the fracture zone is obtained by co-implantation, which in some cases can make the bonding step more sensitive.

Note that a treatment intended to clean the faces of the donor and the support substrates may be used before bringing into intimate contact so as to reinforce the bonding energy.

However, such a cleaning treatment is suitable within the context of the invention only for reduced etching of treated faces, and therefore only having a limited impact on COPs.

Cleaning may be done by a RCA wet cleaning type of chemical surface treatment. The aggressiveness of this RCA treatment may be controlled so that only a small amount of etching is done, for example by monitoring the chemical bath temperature, the exposure time or the product concentration.

In particular, it is worth mentioning that the etching rate of faces subjected to a cleaning treatment is limited (a few Angstroms per minute) and in this respect, the cleaning treatment can be adapted to only cause small amount of etching.

The process according to the invention also comprises a step after the transfer for curing of the vacancy clusters (or COPs) that are present in the transferred thin layer to reduce the first density to a second density.

This curing step is preferably done immediately after the transfer, and in any case preferably before any operation that could increase the size of COPs (for example such as sacrificial oxidation of the thin layer).

According to one possible embodiment, this curing step is performed by carrying out a thermal annealing of the structure obtained after the transfer.

This step can cure the thin layer transferred from the donor substrate to the support substrate of the small COPs. COPs present in a layer with a thickness of up to 5 μm can be cured by annealing, for example under a non-oxidising atmosphere. The high mobility of interstitial atoms present in the volume of the layer then enables reconstruction of the crystal at the COPs which are thus eliminated.

For example, this annealing under a non-oxidising atmosphere (for example under a neutral and / or reducing atmosphere, and particularly under an atmosphere containing argon and / or hydrogen) of the structure obtained after detachment may be a high temperature RTP (Rapid Thermal Processing) annealing according to which the structure obtained after the transfer is heat treated individually, or a thermal annealing performed in a furnace in which different structures are treated in batch.

RTP annealing may be an RTA (Rapid Treatment Annealing) type of annealing done under an atmosphere containing pure hydrogen, pure argon or a hydrogen / argon mix. The annealing temperature is typically

between 1050 and 1250°C, and the annealing duration is typically less than 60 seconds.

Annealing in the furnace may be done at a temperature between 900°C and 1200°C for several hours, under an atmosphere containing pure hydrogen, pure argon or hydrogen / argon mix.

Yet another example of thermal annealing is smoothing annealing done under an atmosphere containing hydrogen and hydrochloric acid, for example like that presented in document US2002090818. This type of smoothing annealing may be an RTA type fast annealing, or of the epitaxy equipment type (duration between a few seconds and a few minutes), the structure obtained after detachment then being treated individually. Smoothing annealing may be done in a furnace (of the order of a few hours), different structures being then treated in batch.

The thermal budget of this curing by thermal annealing (in other words particularly the annealing duration and temperature) is adapted as a function of the selected annealing type, the size of the COPs (which as we have already seen above depends particularly on the pulling rate and the cooling rate), the thickness of the thin layer and whether or not nitrogen doping is done. It will be noted that the curing annealing is more efficient when the COPs are smaller.

Note also that these annealing operations also have a smoothing effect on the surface of the thin layer (by reconstruction of the crystal on a smooth, non-oxidised surface).

Therefore according to this thermal annealing step, the density of COPs in the thin layer is strongly reduced.

Figure 2 shows a thin layer transferred to a donor substrate at the left, from an initial substrate of the type obtained by fast pulling and containing about 2000 COPs ("first density"). After the curing step, the thin layer (shown at the right) only contains about fifty defects ("second density"), that is 40 times less.

Following the COPs curing step, the oxidation, etching and polishing type steps can then be done as is conventionally the case in a SMARTCUT® type transfer process.

Note also that the thermal annealing step adapted to cure COPs has a thermal budget such that the said step is also suitable for reinforcing the bonding interface between the thin layer and the support substrate.

One recognised advantage of a SMARTCUT® type transfer process is the possibility of recycling the donor substrate, either to form a new donor substrate from which a new active layer will be formed and transferred, or to make a new support substrate.

In the context of this invention, the process may include a treatment step of the donor substrate, after transfer of the thin layer onto the support substrate, adapted to enable recycling of the substrate (in other words reusing it in the transfer process).

According to a first embodiment, this treatment step is adapted to enable recycling of the donor

substrate so that it can be used again as a donor substrate. This treatment step restores a surface condition compatible with a new taking off of a thin layer and is done without implementing operations that could increase the size of vacancy clusters present in this substrate. For example, this treatment step may include adapted polishing operations (CMP) and / or cleaning operations, in a similar way as for the pre-bonding cleaning treatment mentioned above, so as to only have a limited impact on COPs, for example by limiting the action of the chemical products used.

According to a second embodiment, the treatment step is adapted to enable recycling of the donor substrate so that it can be used as a support substrate in making a new semiconductor on insulator substrate. In this case, the treatment step is designed to restore a surface condition compatible with molecular bonding (which typically requires a surface roughness less than 5 angstroms RMS).

During this recycling treatment step, the amount of material removed within the thickness of the recycled substrate must be limited to less than 10 microns so that the thickness of the final SeOI wafer (after recycling) remains within the imposed thickness ranges (typically +/10 microns for a 775 micron wafer).

In the context of this second embodiment, greater freedom is provided about the choice of operations that can be done during the recycling treatment. The size and density of COPs in the support substrate only has a limited impact on the quality of the final SeOI

substrate. Therefore, it is possible to use substrates with a COP density equivalent to or even greater than the density of COPs in the initial substrate (for example more than 1.5 COP/cm² or even more than 3 COP/cm²; which for a 300 mm wafer is equivalent to more than 1000 or even 2000 COPs respectively).

Obviously, this invention is in no way limited to the embodiments described and represented, but those skilled in the art would be capable of adding many variants or modifications.

In particular, for making an SOI substrate, the donor substrate is obviously formed by cutting a silicon ingot.

Furthermore, the invention is not limited to the CZ pulling process, but can be used with any type of ingot pulling process.

Finally, it will be understood that the invention is in no way limited to a given wafer diameter, and is applicable to all wafer diameters.

CLAIMS

1. A process for making a semiconductor on insulator substrate comprising an insulating layer inserted between a thin layer made of a semiconducting material and a support substrate, the thin layer resulting from the transfer onto the support substrate of a part of a donor substrate, vacancy clusters being present within the support substrate at a first density, characterized in that it comprises :

- before transfer of said part of the donor substrate onto the support substrate, a forming step of the insulating layer adapted not to increase the size of the vacancy clusters present in said part of the donor substrate at said first density,
- and after the transfer, a curing step of the vacancy clusters present in said part of the donor substrate transferred onto the support substrate to reduce the first density to a second density.

2. A process according to claim 1, characterised in that the forming step of the insulating layer is performed by thermal oxidation of the support substrate.

3. A process according to claim 1, characterised in that the forming step of the insulating layer is performed by deposition of an oxide layer on the donor substrate and / or the support substrate.

4. A process according to any one of the preceding claims, characterised in that the curing step is performed immediately after transfer.

5. A process according to any one of the preceding claims, characterised in that the curing step of vacancy clusters is performed by applying a thermal annealing to the structure obtained after transfer.

6. A process according to claim 5, characterised in that the thermal annealing is performed under a non-oxidising atmosphere.

7. A process according to claim 6, characterised in that the thermal annealing is a rapid thermal processing (RTP).

8. A process according to claim 6, characterised in that the thermal annealing is performed in a furnace.

9. A process according to any one of claims 6 to 8, characterised in that annealing is performed under an atmosphere containing pure hydrogen, pure argon or a hydrogen / argon mix.

10. A process according to any one of claims 6 to 8, characterised in that annealing is a smoothing annealing performed under an atmosphere containing hydrogen and hydrochloric acid.

11. A process according to any one of claims 1 to 10, characterised in that the donor substrate is a substrate formed by cutting an ingot of said semiconducting material obtained by pulling creating vacancy clusters with an average size less than the size of clusters present in a near perfect substrate formed by cutting an ingot obtained by slow pulling.

12. A process according to claim 11, characterised in that the donor substrate is formed by cutting an ingot obtained by CZ pulling such that the density of

clusters of created vacancies larger than 0.14 μm is less than 0.01/cm^2.

13. A process according to any one of claims 1 to 10, characterised in that it comprises a prior step for preparation of the donor substrate including the following operations:

- a step to make an ingot of semiconducting material by pulling creating vacancy clusters with an average size less than the average size of clusters present in a near perfect substrate obtained by slow pulling,

- and a step to cut out the donor substrate in this ingot.

14. A process according to any one of claims 11 to 13, characterised in that the donor substrate is formed by cutting an ingot obtained by CZ pulling such that the density of created clusters of vacancies smaller than 0.2 μm is greater than 1.5/cm^2.

15. A process according to any one of claims 11 to 14, characterised in that the donor substrate is formed by cutting an ingot obtained by CZ pulling such that the density of created clusters of vacancies smaller than 0.12 μm is greater than 3/cm^2.

16. A process according to any one of claims 11 to 15, characterised in that the donor substrate is formed by cutting an ingot obtained by a CZ process by pulling at a speed at least 1.2 times greater than the speed of the said slow pulling to obtain a near perfect crystal.

17. A process according to any one of claims 11 to 16, characterised in that the donor substrate is formed by cutting an ingot subjected to fast cooling.

18. A process according to any one of claims 11 to 17, characterised in that the donor substrate is formed by cutting an ingot subjected to nitrogen doping.

19. A process according to any one of the preceding claims, characterised in that it comprises a step consisting of creating a weakness zone within the thickness of the donor substrate without the said donor substrate having been previously submitted to a cleaning treatment.

20. A process according to claim 19, characterised in that before the step of creating a weakness zone, it includes a step consisting of depositing an oxide layer on the donor substrate surface to form a protection layer, the said protection layer possibly being removed once the weakness zone has been created.

21. A process according to any one of the preceding claims, characterised in that the donor substrate is made of silicon.

22. A process according to any one of the preceding claims, characterised in that the support substrate is obtained in the same way as the donor substrate.

23. A process for making for making a substrate comprising a thin layer of semiconducting material and a support substrate, the thin layer resulting from the transfer onto the support substrate of a part of a donor substrate, vacancy clusters being present within the support substrate at a first density, characterized in that it comprises :

- after transfer of said part of the donor substrate onto the support substrate, a curing step of the vacancy clusters present said part

of the donor substrate transferred onto the support substrate to reduce the first density to a second density.

- and before said curing step, one or several steps adapted so as not to increase the size of the vacancy clusters present in the said part of the donor substrate at the first density.

24. A semiconductor on insulator substrate comprising an insulating layer inserted between a thin layer of semiconducting material and a support substrate, obtained by the process according to any one of the previous claims, starting from a donor substrate with a density of vacancy clusters equal to approximately 3/cm², characterised in that the thin layer has a density of vacancy clusters less than or equal to approximately 0.075/cm².

25. A substrate according to claim 24, characterised in that the support substrate has a density of vacancy clusters greater than or equal to approximately 3/cm².

26. A process for recycling a substrate with vacancy clusters and having been used as a donor substrate from which a thin layer was taken and transferred onto a support substrate, characterised in that it consists in one or several steps adapted so as not to increase the size of the vacancy clusters present in said substrate.

PROCESS FOR TRANSFER OF A THIN LAYER FORMED IN A SUBSTRATE WITH VACANCY CLUSTERS

ABSTRACT OF THE DISCLOSURE

According to a first aspect the invention relates to a process for making a substrate comprising a thin layer of semiconducting material and a support substrate, the thin layer resulting from the transfer to the support substrate of a part of a donor substrate with vacancy clusters at a first density, characterised in that it comprises:

- after transfer of said part of the donor substrate to the support substrate, a curing step of the vacancy clusters present in the part of the donor substrate transferred onto the support substrate to reduce the first density to a second density;
- and before the said curing step, one or several steps adapted so as not to increase the size of the vacancy clusters present in said part of the support substrate at said first density.

The invention also relates to a SeOI substrate obtained by this process, and a process for recycling a substrate with vacancy clusters and having been used as a donor substrate from which a thin layer was taken and transferred onto a support substrate.

Figure 1