METHOD FOR CURING DEFECTS IN A SEMICONDUCTOR LAYER

The present invention relates to a method for curing defects in a semiconductor layer.

The Smart Cut™ method is widely employed in the methods for fabrication of semiconductor structures, for transferring a layer from a substrate referred to as donor to a substrate referred to as receiver.

Generally speaking, this method comprises a step for implantation of ion species into the donor substrate.

The implantation profile in the donor substrate is of the Gaussian type, with a peak in a plane corresponding to a plane at a certain depth with a maximum of implanted species, forming a fragilization region in the donor substrate.

The layer to be transferred is bounded between the surface of the donor substrate through which the implantation has been carried out and the fragilization region.

The Smart Cut™ method subsequently comprises a step for assembling the donor substrate with the receiver substrate, the layer to be transferred being brought into contact with the receiver substrate.

Then, mechanical, thermal or other forces are applied in such a manner as to fracture the donor substrate along the fragilization region.

The remainder of the donor substrate, which could be recycled, and the final semiconductor structure which comprises the receiver substrate and the transferred layer are separated.

However, after the transfer, defects subsist in the transferred layer that are associated with the implantation and with the fracture that has been carried out in the donor substrate in order to form the fragilization region.

These defects can typically comprise defects in the crystal lattice of the transferred layer, together with residues of the implanted species, etc.

Such defects are capable of altering the operation of the electronic devices formed in or on the transferred layer.

In order to cure these defects, a known solution is to apply to the semiconductor structure thus formed a thermal treatment at high temperature.

In this respect, reference could be made to the document US 6,403,450 which describes a method for curing post-fracture defects that comprises an oxidation of the surface of the transferred layer followed by a thermal treatment at a temperature of around 1100°C.

However, there are situations in which it is not possible to apply a thermal treatment at such a high temperature.

This is notably the case when the receiver substrate is a substrate having been previously processed so as to comprise electronic devices, interconnections, metallized regions, etc., which would be altered by the application of a thermal treatment at a high temperature, in other words greater than around 500°C.

This is also the case when the transferred layer itself cannot be exposed to high temperatures, such as for example when this layer comprises a PN junction which would be damaged if it were exposed to temperatures exceeding 800°C (owing to the diffusion of the dopants in the layers forming the junction).

The document US 2005/0280155 discloses one example of a method in which a semiconductor layer comprising a PN junction is transferred onto a receiver substrate comprising electronic devices and an interconnection region comprising metallized portions, where the transfer of the semiconductor layer may be carried out by the Smart Cut™ method.

Such a receiver substrate must not therefore be exposed to a high temperature.

However, the application of a thermal treatment at a lower temperature, in other words lower than around 500°C, or the application of conditioning processing steps not implementing any thermal treatment (polishing, etc.), so as to avoid damaging the receiver substrate, might not be sufficient to cure all the defects in the transferred layer.

This insufficient or incomplete curing of the defects compromises the operation of devices formed later on in or on the transferred layer.

In particular, since the implantation notably has the effect of de-activating certain types of dopants, the PN junction that it contains risks no longer being operational.

The aim of the present invention is to overcome these problems and, more particularly, to provide a method for curing defects due to the implantation into the transferred layer, which does not risk damaging the receiver substrate, whatever the devices or functions present in the said receiver substrate.

According to the invention, a method is provided for curing defects associated with the implantation of atomic species in a semiconductor layer transferred onto a receiver substrate, the semiconductor layer being thermally insulated from the receiver substrate by a layer whose thermal conductivity is lower than the thermal conductivity of the transferred

semiconductor layer, the said method being characterized in that it comprises the application to the semiconductor layer of a selective electromagnetic irradiation implemented so as to heat up the semiconductor layer to a temperature lower than the temperature of fusion of the said layer without causing an increase in the temperature of the receiver substrate beyond 500°C.

In a particularly advantageous manner, the wavelength of the said selective electromagnetic irradiation is chosen such that only the transferred semiconductor layer absorbs the said irradiation.

According to one preferred embodiment of the invention, the said electromagnetic irradiation is a pulsed-laser irradiation, the energy density and the duration of the said pulses being chosen so as to heat up the semiconductor layer to a temperature lower than the temperature of fusion of the said layer for curing the defects without causing an increase in the temperature of the receiver substrate beyond 500°C.

According to one particular embodiment, the transferred semiconductor layer is made of silicon and the wavelength of the irradiation is shorter than 360 nm.

In this case, the energy and the duration of the pulses are preferably chosen to raise the said transferred layer to a temperature in the range between 800 and 1300°C.

Furthermore, the receiver substrate can advantageously comprise at least one electronic device and/or one functionalized region and/or one metallized region.

According to one particularly advantageous embodiment of the invention, the transferred layer is a layer of silicon comprising an electrically functional portion. The curing method according to the invention therefore allows the electrical functionalities of the said transferred layer, which may have been damaged by the implantation, to be reactivated.

Preferably, the layer whose thermal conductivity is lower than the thermal conductivity of the transferred semiconductor layer has a thickness in the range between 10 and 10000 nm.

The invention also relates to a method for fabrication of a semiconductor structure comprising a receiver substrate and a semiconductor layer, the said method comprising:

- the implantation of atomic species into a donor substrate, so as to create a fragilization region bounding the semiconductor layer to be transferred,
- the formation, on the donor substrate and/or the receiver substrate, of a layer whose thermal conductivity is lower than the thermal conductivity of the semiconductor layer,
- the bonding of the donor substrate onto the receiver substrate, the said layer whose thermal conductivity is lower than the thermal conductivity of the semiconductor layer thermally insulating the receiver substrate from the semiconductor layer,

- the fracture of the donor substrate along the fragilization region, so as to transfer the semiconductor layer onto the receiver substrate,

- the application of the method for curing defects such as described hereinabove to the transferred semiconductor layer for curing the defects associated with the implantation into the said layer.

Advantageously, between the steps for fracture and for curing of the defects, a polishing of the surface of the transferred semiconductor layer is carried out.

According to one particular embodiment, the donor substrate is bonded onto the receiver substrate by means of a bonding layer whose thermal conductivity is greater than or equal to the thermal conductivity of the semiconductor layer.

For example, the said bonding layer comprises a layer of silicon and/or a metal layer, so as to provide an electrically-conducting interface between the receiver substrate and the transferred thin film.

According to one particular embodiment of the invention, the layer whose thermal conductivity is lower than the thermal conductivity of the semiconductor layer is discontinuous.

Another subject of the invention relates to a semiconductor structure comprising a substrate and a semiconductor layer, in which the substrate comprises at least one electronic device and/or functionalized region and/or metallized region and is thermally insulated from the semiconductor layer by a layer having a thermal conductivity lower than the thermal conductivity of the semiconductor layer, the said structure being characterized in that the semiconductor layer comprises a portion having a P-type donor concentration higher than 10^{17} cm^{-3}. Such a structure is advantageously obtained by the method for curing defects according to the invention, which allows the P-type dopants contained in the semiconductor layer to be reactivated.

Others features and advantages of the invention will become apparent from the detailed description that follows, presented with reference to the appended drawings in which:

- Figures 1A to 1D illustrate schematically the various steps for transferring a semiconductor layer onto a functionalized receiver substrate by the Smart Cut™ method,
- Figure 2 shows the curve of the coefficient of absorption in silicon as a function of the wavelength of the radiation,
- Figure 3 illustrates a structure of the semiconductor-on-insulator type obtained by the Smart Cut™ method,

- Figures 4A and 4B respectively show the temperature profiles in the structure in Figure 3 with a JPSA laser and with an Excico laser as a progression of the successive pulses,
- Figures 5A and 5B show the variation over time of the temperature at the surface of the transferred semiconductor layer (curve (a)) and of the receiver substrate (curve (b)) for the structure in Figure 3 with a JPSA laser and with an Excico laser, respectively,
- Figure 6 illustrates a cartography of the power density of the laser as a function of the thickness of the transferred layer and of the thickness of the bonding layer,
- Figure 7 shows the variation of the width of the Raman peak as a function of the energy density of the laser for various structures treated by laser or otherwise,
- Figure 8 illustrates the variation of the dopant concentration of the transferred semiconductor layer through the various steps of the method.

It should be noted that, in the diagrams of the structures, the ratios of thicknesses between the various layers are not necessarily adhered to in order to facilitate their representation.

Figures 1A to 1D illustrate the successive steps in the fabrication of a structure comprising a semiconductor layer 10 on a receiver substrate 2 by transfer of the said layer 10 from a donor substrate 1.

With reference to Figure 1A, a fragilization region 11 is formed by implantation of species (schematically represented by the arrows) into the donor substrate 1 comprising the layer 11 to be transferred.

The donor substrate 1 can be a bulk substrate or else a composite substrate, in other words composed of a stack of layers of various materials.

The layer 11 to be transferred is a single-crystal layer of a semiconductor material, for example silicon, germanium, SiGe, III-V binary, ternary, quaternary, or even higher order alloys.

It may also be composed of a stack of such layers.

For example, the transferred layer can be a layer of silicon comprising a PN junction.

The implanted species are typically light atoms, such as, preferably, hydrogen or helium.

A single species can be implanted (for example, hydrogen only), however, alternatively, a co-implantation of two species (for example hydrogen + helium), simultaneously or successively, may be preferred.

The species implanted into the donor substrate are distributed according to an implantation profile which typically has a Gaussian shape; the fragilization region 11 is located at the implantation peak.

Those skilled in the art are familiar with the implantation doses and energies for forming the fragilization region 11 at a given depth (corresponding to the thickness of the layer 10 to be transferred) depending on the material of the donor substrate 1 and on the species to be implanted.

In a second step (Figure 1B) the fragilized donor substrate 1 is bonded onto a receiver substrate 2.

In the figure presented here, the receiver substrate 2 is shown with functionalized regions 20 which may comprise metallized regions, interconnections, or conducting links.

For this reason, the receiver substrate 2 must not be subjected to high temperatures in order to avoid any damage to these functionalities.

Alternatively, the substrate 2 can be a bulk or composite substrate made of one or more materials, semiconductors or otherwise, according to the application of the final semiconductor structure.

A thermally insulating layer 3, in other words whose thermal conductivity is lower than the thermal conductivity of the transferred semiconductor layer 10, is inserted between the said transferred layer 10 and the receiver substrate 2.

The said layer 3 allows the receiver substrate to be thermally isolated from the transferred layer, such that when the transferred layer is heated up to a high temperature, lower than its temperature of fusion, the increase in temperature in the receiver substrate remains lower than 500°C.

Furthermore, the said layer 3 allows the energy needed for the heating of the transferred layer 10 to be minimized, since this heating is confined to the transferred layer which is relatively thin.

In order to fulfil these functions, the said thermally insulating layer 3 advantageously has a thickness in the range between 10 and 10000 nm, preferably between 50 and 1000 nm.

The said layer 3 is advantageously composed of an oxide, for example SiO_2.

However, any other material whose thermal conductivity is lower than that of the material of the semiconductor layer 10 may be employed, such as SiO_2, Al_2O_3, SiN, HfO_2, TiO_2, etc.

The layer 3 can be uniform (formed from a single material or from a stack of layers) or non-uniform, in other words formed from complementary patterns, each of the patterns being formed from a thermally insulating material.

The said layer 3 may be continuous, in other words spread over the whole surface of the receiver substrate or of the transferred layer.

Alternatively (not shown), the said layer can be discontinuous, in other words only formed from an insulating material over certain areas of the surface of the receiver substrate or of the transferred layer, in particular facing areas of the receiver substrate that must necessarily be maintained at a temperature lower than 500°C.

According to one particular embodiment, the said layer 3 also constitutes a bonding layer formed between the donor substrate 1 and the receiver substrate 2.

In particular, the said bonding layer can allow the bonding energy between the two substrates to be increased.

Thus, for example, if the donor substrate and the receiver substrate are made of silicon, the bonding layer can be a layer of SiO_2.

The said layer may be formed before the bonding onto one of the substrates, or else be composed of the assembly of two layers of oxide formed on each of the two substrates.

Alternatively (not shown), a bonding layer separate from the thermally insulating layer can be formed on the donor substrate and/or the receiver substrate.

For example, the bonding layer can comprise a layer of silicon.

According to another embodiment of the invention, the bonding layer can comprise a metal layer, notably when it is desired to form a conducting link between the transferred semiconductor layer and the receiver substrate.

Furthermore, the bonding layer may be continuous (in other words covering the whole surface of the substrates (donor and receiver)) or else discontinuous, in other words only covering a part of the surface of the said substrates, the said bonding layer then being laid out according to a given pattern.

When the bonding layer is not thermally insulating, in other words it has a thermal conductivity greater than or equal to the thermal conductivity of the transferred layer 10 (which is generally the case for a metal layer or for a layer of silicon), prior to the bonding, the thermally insulating layer 3 is formed on or under the bonding layer.

When the bonding layer has a temperature of fusion lower than the temperature of fusion of the transferred semiconductor layer (which can be the case for a metal layer), it is preferable to place the thermally insulating layer between the transferred semiconductor layer and the bonding layer, in such a manner as to avoid a significant increase in temperature of the bonding layer during the heating of the transferred layer.

Alternatively (not shown), a bonding, without bonding layer, of the donor substrate onto the receiver substrate may be carried out, the thermally insulating layer (continuous or discontinuous) being situated at the interface.

Preferably, the bonding is effected by molecular adhesion.

The thermally insulating layer and, where relevant, the bonding layer can be formed by any suitable method, for example by a deposition technique, such as a chemical vapour-phase deposition, or CVD, a physical vapour-phase deposition, or PVD, or an atomic layer deposition, or ALD.

Optionally, the bonding step, whether or not it involves the use of a bonding layer, can be preceded by treatment or processing steps on the surface of the donor substrate and/or of the receiver substrate designed to increase the bonding energy.

Such processing or treatment steps may notably comprise operations for cleaning, chemical etching, polishing, plasma activation, etc.

The bonding may be followed by a thermal treatment designed to reinforce the bonding.

Given that the receiver substrate 2 cannot tolerate high temperatures, this thermal treatment will be conducted at a moderate temperature, for example less than or equal to 500°C.

Subsequently, the donor substrate 1 is caused to fracture along the fragilization region 11 and, after separation from the remainder of the donor substrate, the structure illustrated in Figure 1C is obtained comprising the donor substrate 2, potentially the bonding layer 3 and the transferred semiconductor layer 10.

Since the surface 12 of the transferred layer 10 exhibits a certain roughness after the fracture, it may be advantageous to polish it, for example by a chemical-mechanical polishing (CMP) process, in order to reduce its roughness.

With reference to Figure 1D, a thermal treatment is applied which is localized to the transferred layer 10, in other words which does not lead to the rest of the structure being significantly heated up.

The aim of the said thermal treatment is to cure the defects in the transferred layer 10 which are associated with the implantation, without causing the said transferred layer 10 to melt.

For example, when the transferred layer is a layer of silicon comprising one or more p-n junctions, the effect of the implantation is to electrically deactivate the dopants used to form the said junction.

Notably, it is known that the implantation of hydrogen leads to a doping of the n type for a layer of silicon.

Such a doping can degrade the electrical performance of the layer, in particular if the initial doping of the layer is of the p type, or if the layer comprises a portion having a p-type doping, which is the case in a junction.

Thanks to the treatment according to the invention, the curing of the defects associated with the implantation and with the fracture allows the dopants to be reactivated.

In contrast to the thermal treatments of the prior art, which lead to a heating of the whole of the semiconductor structure, the invention provides a localized thermal treatment of the transferred layer, avoiding the heating of the receiver substrate, or at the very least to heat it in a sufficiently moderated manner so as not to alter the devices or functions that it comprises (this also applying, where relevant, to the bonding layer if it is sensitive to temperature).

For this purpose, the solution of the invention is to apply an electromagnetic irradiation by pulses to the transferred layer.

The parameters of this irradiation are presented in detail hereinbelow.

Parameters of the irradiation

Wavelength

The wavelength of the irradiation is chosen such that the radiation is totally or substantially totally absorbed by the transferred layer 10.

This allows the heating caused by the irradiation to be localized at the transferred layer 10 and the temperature of the receiver substrate 2 to remain below a temperature beyond which the devices or functions that it comprises would be altered.

As previously mentioned, when the bonding layer has a temperature of fusion lower than the temperature of fusion of the transferred semiconductor layer (which can be the case for a metal layer), it is preferable to place the thermally insulating layer between the transferred semiconductor layer and the bonding layer, in such a manner that the bonding layer is raised to a temperature substantially lower than its temperature of fusion.

Furthermore, the radiation absorbed by the transferred layer must lead to a temperature of the transferred layer that remains below the temperature of fusion of the said layer.

Indeed, during this treatment, this solution tries to avoid melting the transferred layer so as not to risk the generation of the crystal defects in the said layer which would be due to a mechanism of fusion – re-crystallization. Such defects would be likely to deteriorate the electrical performance of the transferred layer.

Figure 2 illustrates the curve of the coefficient of absorption α in silicon as a function of the wavelength λ.

It can be deduced from this curve that, in order to avoid the radiation being transmitted to the receiver substrate, the wavelength of the laser must be shorter than 360 nm. This is because, beyond 360 nm, the coefficient of absorption decreases, which means that the radiation passes through the transferred layer to reach the underlying layers and to heat them up.

Duration of the pulses

The duration of the pulses is chosen so as, on the one hand, to be sufficiently long to provide the energy that is sufficient to cure the defects due to the implantation into the transferred layer 10 and, on the other hand, sufficiently short so as not to produce a significant increase in the temperature of the receiver substrate 2.

In addition, the time interval between two pulses is chosen to be longer than the time needed for diffusing the heat in the silicon.

For example, if the receiver substrate comprises a metallized region, the increase in temperature must not exceed the temperature of fusion of the metal.

Typically, for a transferred layer 10 whose thickness is of the order of a micrometer, the order of magnitude of the duration of the pulse is around ten nanoseconds.

By way of example, the lasers currently on the market offer pulse durations in the range between 10 and 200 ns.

Power

The power delivered by the laser must theoretically be sufficient to allow the transferred layer to be heated during each pulse.

In practice, it is possible to focus the laser beam such that the energy per unit surface area delivered reaches the required level.

The only limitation of this focussing technique is the size of the focus spot which, if it is very small, has a negative effect on the efficiency of the method.

One notable advantage of the thermally insulating layer 3 (whether continuous or discontinuous) is that it allows the energy provided by the laser to be confined only to the transferred layer 10 whose thickness is small with respect to the total thickness of the structure.

This allows a laser with a moderate power to be used, which is in any respect readily accessible with the industrial devices currently present on the market.

<u>Example of implementation of the invention</u>

By way of example, the silicon-on-insulator (SOI) structure illustrated in Figure 3 is fabricated by the Smart Cut™ method, which structure successively comprises a receiver substrate 2’ made of bulk silicon, whose thickness is a few hundreds of micrometers, a

thermally insulating bonding layer 3' of silicon dioxide having a thickness of 145 nm (referred to as a BOX, acronym for the term "Buried OXide"), and a transferred layer 10 of single-crystal silicon having a thickness of 0.8 μm. The conditions used for the fabrication of this structure SOI are a hydrogen implantation with an energy of 122 keV and a dose of $8x10^{16}$ at/cm^2.

After the fracture, the transferred layer 10 of silicon is damaged by defects associated with the implantation and with the fracture.

A large part of these defects is eliminated by the application of a chemical-mechanical polishing (CMP), but the residual defects degrade the crystallinity of the silicon and are detrimental to the performance of the electronic devices which are subsequently to be formed in or on the transferred layer.

An irradiation by laser is applied to two identical semiconductor structures.

The first treatment step is an irradiation with a laser marketed by the company JPSA, with a wavelength of 193 nm and a pulse duration of 20 ns FWHM (Full-Width Half-Max).

The second treatment is an irradiation with a laser marketed by the company Excico, with a wavelength of 308 nm and a pulse duration of 160 ns FWHM.

In order to heat a surface portion (in other words localized at the transferred layer 10) of the semiconductor structure to a temperature lower than the temperature of fusion of the silicon, the energy per unit surface area of the lasers is respectively limited to 0.16 J/cm^2 for the first laser and to 0.7 J/cm^2 for the second.

Simulations, which consist of the resolution of the heat equation for transient conduction in a multilayer and take into account the transient nature of the pulsed laser, can be developed.

Results of these simulations are presented in Figures 4A and 4B, which show the temperature profiles in each of the layers 10, 3', 2' of the semiconductor structure at various times.

The abscissa axis shows the depth in the structure, the origin corresponding to the free surface 12 of the transferred semiconductor layer 10.

Figure 4A shows the temperature profiles in the semiconductor structure in the case of the first treatment; the curves (c1) to (c5) show the increase in the temperature every 5 ns until the end of the laser pulse.

Figure 4B shows the temperature profiles in the semiconductor structure in the case of the second treatment; the curves (c1) to (c20) show the increase in the temperature every 10 ns until the end of the laser pulse.

In the two cases, it can be observed that, even at these relatively low power levels, the heating is confined to the transferred semiconductor layer 10 and that it is possible to reach, in a few pulses, a temperature close to but lower than the temperature of fusion of silicon, suitable for curing the defects associated with the implantation.

On the other hand, even if over time heating of the receiver substrate 2' takes place, this heating does not exceeds 200°C.

These same simulations also allow the time variation of the temperature of the surface of the various layers during one pulse to be observed in the structure illustrated in Figure 3.

Figures 5A and 5B show the variation of the temperature at the surface of the transferred layer 10 (curve (a)) and at the interface between the thermally insulating layer 3' and the receiver substrate 2' (curve (b)), in the case of the first treatment and of the second treatment, respectively.

In the two cases, it is verified that the temperature of the surface of the receiver substrate 2' never exceeds 500°C. In the first case, this temperature does not even exceed 200°C.

For a given pair of thicknesses of transferred layer and of bonding layer, the power density needed to obtain a temperature at the interface between the air and the transferred layer 10 lower than the temperature of fusion of the layer 10 can be adjusted in the simulation.

By scanning a range of thicknesses of transferred layer and of bonding layer, the cartography illustrated in Figure 6 is obtained.

Figure 6 shows a cartography of the power density of the laser as a function of the thickness e_{SOI} of the transferred layer 10 (on the abscissa) and of the thickness e_{BOX} of the thermally insulating layer 3' (on the ordinate), in the case of the first treatment (JPSA laser).

The parameters of the treatment are defined in such a manner that the interface between the air and the transferred layer 10 is heated to a temperature very close to the temperature of fusion of the material of the said layer, but lower than this temperature, whereas the interface between the thermally insulating layer 3' and the receiver substrate 2' remains at a temperature lower than 400°C.

The lower shaded part of the cartography is a region in which the treatment leads to an increase in the temperature of the interface between the thermally insulating layer 3' and the receiver substrate 2' greater than 400°C.

This figure highlights the efficiency of the layer 3' of SiO_2 in terms of thermal insulation of the receiver substrate 2' with respect to the transferred layer.

This figure also shows that, in certain configurations of thicknesses of the transferred layer 10 (5 nm to 200 nm) and of the thermally insulating layer 3' (greater than 50 nm), a relatively modest power density (of around $0.4.10^{11}$ W/cm^2) allows a relatively high temperature to be reached on the surface of the layer 10 without exceeding 400°C in the receiver substrate.

On the upper part of the cartography, various regions can be seen which correspond to various values of the required power density, which is in the range between $0.4.10^{11}$ W/cm^2 and $1.8.10^{11}$ W/cm^2 and which may for example be represented by various colours.

Generally speaking, the greater the thickness of the thermally insulating layer 3, 3', the lower the energy that must be provided by the laser for heating the surface of the transferred layer to the required temperature.

If the thermally insulating layer were too thin, it would not be possible to raise the surface of the transferred layer to a high temperature lower than the temperature of fusion of the silicon while maintaining the interface of the said layer with the receiver substrate at a temperature lower than 500°C.

Finally, when the transferred layer is very thin (of the order of a nanometre), the optical length is small, which requires a higher power beam to reach the temperature for curing the defects lower than the temperature of fusion of the silicon.

The curing of the defects by laser treatment can be observed by various techniques.

In particular, Raman spectroscopy allows the crystallinity of the transferred layer to be characterized by means of the width of the peak at half-height (FWHM).

Figure 7 illustrates the improvement in the crystallinity of the silicon of the transferred layer 10 as a function of the energy density F of the laser, the ordinate axis being the width W (cm^{-1}) of the peak at half-height for the Raman UV spectroscopy.

The curve (a) corresponds to the first laser treatment applied to the semiconductor structure in Figure 3 in which H+ ions had been implanted through the layer to be transferred.

The curve (b) corresponds to the second laser treatment applied to the semiconductor structure in Figure 3 in which H+ ions had been implanted through the layer to be transferred.

The curve (c) corresponds to the second laser treatment applied to the semiconductor structure in Figure 3 in which an He/H+ co-implantation had been carried out through the layer to be transferred.

It is observed that the crystalline quality increases (i.e. the width of the peak decreases) when the energy density of the laser increases.

Thus, for a high energy density, in the transferred layer, a crystalline quality similar to that of bulk silicon (reference material represented by the point Si) and to that of a layer of

silicon in an SOI having undergone a thermal treatment at a temperature higher then 1000°C is obtained.

Figure 8 illustrates the restoration of the activation of the dopants in the case where the transferred layer is a layer of silicon comprising a PN junction.

In this graph, the ordinate axis corresponds to the level of doping n (expressed in cm^{-3}) in the transferred layer. The squares correspond to the P doping, the triangles to the N doping.

The abscissae correspond to the successive implantation, fracture and curing steps for the defects by the laser irradiation.

Prior to the implantation (step 1), the N doping is at a density of around 5.10^{17} cm^{-3}, whereas the P doping is around 8.10^{19} cm^{-3}.

The implantation, whether this be implantation of H+ ions (step 2) or co-implantation of He/H+ ions (step 2'), has the effect of de-activating the dopants, which results in a significant decrease in the level of doping n.

This de-activation is also observed after fracture (step 3 corresponding to the fracture preceded by the implantation of H+ or step 3' corresponding to the fracture preceded by the H+/He co-implantation) and after polishing (step 4 corresponding to the polishing of the transferred layer having undergone the implantation of H+ or step 4' corresponding to the polishing of the transferred layer having undergone H+/He co-implantation).

The laser treatment has the effect of restoring the dopants.

Thus, the step 5 consists in applying a laser treatment with an energy density of 0.65 J/cm^2 to the transferred layer having undergone the implantation of H+.

The step 5' relates to the same laser treatment applied to the transferred layer having undergone H+/He co-implantation.

The invention therefore allows a structure to be obtained in which the transferred semiconductor layer comprises a portion having a P-type donor concentration greater than 10^{17} cm^{-3}, which could not be obtained with the methods of the prior art when it was not possible to expose the receiver substrate to a temperature higher than 500°C.

Lastly, it goes without saying that the examples that have just been presented are only particular illustrations and are in no way limiting with regard to the fields of application of the invention, notably as regards the nature and the materials of the semiconductor structure treated.

In particular, the invention is advantageously applicable to semiconductor structures fabricated by the Smart Cut™ method in which the receiver substrate must not be exposed to temperatures that are too high.

However, the invention is also applicable to structures whose receiver substrate is not subject to such limitations; for example a “conventional” SOI structure in which the receiver substrate is, for example, a bulk silicon substrate.

CLAIMS

1. Method for curing defects associated with the implantation of atomic species into a semiconductor layer (10) transferred onto a receiver substrate (2), the semiconductor layer (10) being thermally insulated from the receiver substrate (2) by a layer (3, 3') whose thermal conductivity is lower than the thermal conductivity of the transferred semiconductor layer (10), the said method being characterized in that it comprises the application to the semiconductor layer (10) of a selective electromagnetic irradiation implemented so as to heat up the semiconductor layer (10) to a temperature lower than the temperature of fusion of the said layer (10) without causing an increase in the temperature of the receiver substrate (2) beyond 500°C.

2. Method according to Claim 1, characterized in that the wavelength of the said selective electromagnetic irradiation is chosen such that only the transferred semiconductor layer (10) absorbs the said irradiation.

3. Method according to Claim 2, characterized in that the said electromagnetic irradiation is a pulsed-laser irradiation, the energy density and the duration of the said pulses being chosen so as to heat the semiconductor layer (10) to a temperature lower than the temperature of fusion of the said layer (10) without causing an increase in the temperature of the receiver substrate (2) beyond 500°C.

4. Method according to Claim 3, characterized in that the transferred semiconductor layer (10) is made of silicon and in that the wavelength of the irradiation is shorter than 360 nm.

5. Method according to Claim 4, characterized in that the energy and the duration of the pulses are chosen so as to raise the said transferred layer (10) to a temperature in the range between 800 and 1300°C.

6. Method according to one of Claims 1 to 5, characterized in that the receiver substrate (2) comprises at least one electronic device and/or one functionalized region and/or one metallized region.

7. Method according to one of Claims 1 to 6, characterized in that the transferred layer (10) is a layer of silicon comprising an electrically functional portion.

8. Method according to one of Claims 1 to 7, characterized in that the layer (3, 3') whose thermal conductivity is lower than the thermal conductivity of the transferred semiconductor layer (10) has a thickness in the range between 10 and 10000 nm.

9. Method for fabrication of a semiconductor structure comprising a receiver substrate (2) and a semiconductor layer (10), the said method comprising:

- the implantation of atomic species into a donor substrate (1), so as to create a fragilization region (11) bounding the semiconductor layer (10) to be transferred,
- the formation, on the donor substrate (1) and/or the receiver substrate (2), of a layer (3, 3') whose thermal conductivity is lower than the thermal conductivity of the semiconductor layer (10),
- the bonding of the donor substrate (1) onto the receiver substrate (2), the said layer (3, 3') whose thermal conductivity is lower than the thermal conductivity of the semiconductor layer (10) thermally insulating the receiver substrate (2) from the semiconductor layer (10),
- the fracture of the donor substrate (1) along the fragilization region (11), so as to transfer the semiconductor layer (10) onto the receiver substrate (2),
- the application of the method according to one of Claims 1 to 8 to the transferred semiconductor layer (10) for curing the defects associated with the implantation into the said layer (10).

10. Method according to Claim 9, characterized in that, between the steps for fracture and for curing defects, a polishing of the surface (12) of the transferred semiconductor layer (10) is carried out.

11. Method according to one of Claims 9 or 10, characterized in that the donor substrate (1) is bonded onto the receiver substrate (2) by means of a bonding layer whose thermal conductivity is greater than or equal to the thermal conductivity of the semiconductor layer (10) .

12. Method according to Claim 11, characterized in that the said bonding layer comprises a layer of silicon and/or a metal layer.

13. Method according to one of Claims 9 to 12, characterized in that the layer (3, 3') whose thermal conductivity is lower than the thermal conductivity of the semiconductor layer (10) is discontinuous.

14. Semiconductor structure comprising a substrate (2) and a semiconductor layer (10), in which the substrate (2) comprises at least one electronic device and/or one functionalized region and/or one metallized region and is thermally insulated from the semiconductor layer (10) by a layer (3, 3') having a thermal conductivity lower than the thermal conductivity of the semiconductor layer (10), the said structure being characterized in that the semiconductor layer (10) comprises a portion having a P-type donor concentration higher than 10^{17} cm^{-3}.