

METHOD FOR FABRICATING A SEMICONDUCTOR SUBSTRATE

This invention relates to a method for fabricating a semiconductor substrate, in particular, to a semiconductor on insulator substrate (SOI) comprising an additional doped layer, in particular an epitaxial layer, suitable for opto electronic applications, such as image sensors.

In optoelectronics, special substrates are necessary which are, for example, used for image sensors, like backside illuminated CMOS Image Sensors (BCIS), which find their application in video or photographic cameras. In these substrates, photons can be collected by the image sensors formed in the device layer of an SOI substrate. In some devices, the SOI device layer containing the image sensors is transferred to a final substrate to expose the backside of the sensors and facilitate the efficient collection of photons.

In the prior art, this kind of special SOI substrate was prepared using an n-type donor substrate, to form an n-type SOI layer in the conventional Smart Cut™ technology. This method typically comprises the steps of providing a donor substrate, e.g. a silicon wafer, providing an insulating layer on the donor substrate and creating a predetermined splitting area inside the donor substrate, which is achieved by implanting atomic species or ions, such as helium or hydrogen ions, into the donor substrate. In the next step, the donor substrate is bonded to a base substrate, e.g. a further silicon wafer, such that the insulating layer is sandwiched between the handle and the donor substrate. Subsequently, the remainder of the donor substrate is detached from the bonded donor-base substrate at the predetermined splitting area following a thermal and/or mechanical treatment upon the predetermined splitting area. As a result, a semiconductor on insulator (SOI) substrate is obtained.

However, the use of a first type of dopants (e.g. n-type) substrate in the SOI substrate fabrication line, different to a second type of dopants (e.g. p-type) can lead to cross-contamination from donor wafers with an impurity dopant concentration of the second type used in the standard SOI substrate, to other

wafers having the target dopant type of the first type. Even worse, in case the special substrates for opto-electronic applications need a different type of dopants e.g. n-type dopants (Phosphorous) than the standard substrates, e.g. p-type (Boron), the n-type dopants may contaminate the fabrication line, thereby reducing the quality of the standard SOI substrates. This thus leads to unsatisfying dopant profiles in both the n- SOI wafers and the standard p- SOI wafers.

Surface contamination through airborne contamination is a key concern in this matter. In a standard cleanroom environment with no specific chemical filtering, it is common to have Boron or Phosphorus contamination on surfaces, in the range of 1 to several 10^{12} at/cm² for about 30 min to 2 hours, depending on the air recycling rate. By diffusion, the unwanted elements diffuse into the bulk of a substrate leading to a volume contamination in the of order of 10^{16} at/cm³, which is a particular problem when n- or p- layers are targeted.

In addition, during subsequent annealing steps during the Smart Cut™ process, a diffusion of dopants out of the counter-doped layer occurs which further deteriorates the substrate.

Furthermore, the special substrates with n-type dopants show a rather high density of defects compared to special substrates with a p-type dopant structure. This is related to the fact that n-type starting substrates, on which an additional epitaxial layer will be grown, have a lower quality than p-type substrates, in particular concerning COP defects.

It is therefore the object of the present invention to propose a method for fabricating a semiconductor on insulator substrate with an additional layer with which the contamination problems can be overcome.

This object is achieved with the method for fabricating a semiconductor substrate, in particular a semiconductor on insulator substrate, according to claim 1. Accordingly, the method comprises the steps of: a) providing a first semiconductor substrate with a first impurity density of a first impurity type, b) subjecting the first semiconductor substrate to a first thermal treatment to thereby reduce the first

impurity density in a modified layer adjacent one main surface of the first semiconductor substrate, c) transferring at least partially the modified layer with the reduced first impurity density onto a second substrate, to thereby obtain a modified second substrate, and d) providing a layer, in particular by epitaxial growth, with a second impurity density of a second impurity type different to the first impurity type.

By providing a starting substrate having a different impurity type than the final substrate, one can use the same fabrication line to transfer a layer from the first to the second substrate without risking contamination even in case the final substrate has impurities of a different kind compared to the substrates that are usually fabricated on that same fabrication line.

Furthermore one can choose the substrate with the better qualities as a starting material independently of the final impurity type.

The term "impurity type" relates to n- or p-type impurities. Here the atoms of the second impurity type can either be provided directly during the growth of the additional layer or afterwards.

Preferably, step d) is carried out such that the transferred layer has a third impurity density of the second impurity type. This is either achieved by diffusion, thus unintentionally, or by auto-doping, thus an intentional process. Thus the transferred layer changes its impurity type during the process and it becomes possible to tailor the final dopant profile to the needs of the desired application.

Advantageously, the method can further comprise an additional step e) of subjecting the modified second semiconductor substrate to a second thermal treatment after step c) and before step d). This will further reduce the dopant concentration of the first impurity type in the transferred layer. Thus, even if, during the transfer process, a recontamination of the layer close to the surface of the first substrate occurs, these contaminants can diffuse out during the second thermal treatment before the provision of the layer with the second impurity density.

Preferably, step c) can comprise the sub-steps of: f) creating a predetermined splitting area inside the semiconductor substrate, preferably inside the modified layer with the reduced impurity density, g) attaching, preferably by bonding, the first semiconductor substrate to the second semiconductor substrate to sandwich the reduced first impurity density layer therebetween and h) subjecting the bonded substrate to a thermal and/or mechanical treatment such that detachment occurs at the predetermined splitting area. Thus a Smart Cut™ type layer transfer process can be carried out without risking the contamination of the layer transfer fabrication line, in case substrates with the second impurity type have to be fabricated in a line usually only used for the first impurity type.

According to a preferred embodiment, the method can comprise a further step of providing a dielectric layer on the modified layer with reduced impurity density. This layer can be provided by thermal growth or deposition. As an alternative, the dielectric layer may be provided on the second substrate before the layer transfer. Thus the method is compatible with a standard Smart Cut™ technique, as described above.

According to a preferred embodiment, the remaining part of the first semiconductor substrate obtained during step c) can be reused as a new first semiconductor substrate in a subsequent semiconductor substrate fabricating process comprising at least steps c) and d). Even more preferred, step b) can be carried out such that steps c) and d) can be carried out at least two times without repeating step b). In fact, by carrying out the first thermal treatment such that the modified layer adjacent has a thickness being at least twice the thickness of the transferred layer, it becomes possible to transfer two layers without having to carry out the impurity density reduction step b). This further optimizes the process.

According to a variant, the remaining part of the first semiconductor substrate obtained during step c) can be reused as a new second semiconductor substrate in a subsequent semiconductor substrate fabricating process comprising at least steps c) and d). Thus, in this case, the remainder obtained during step c), can still be reused even in case it cannot be reused as a donor substrate again, so that no material is spoiled.

Preferably, the first and second thermal treatments can be carried out under a neutral atmosphere in particular a helium and/or argon atmosphere. Under these process conditions, the diffusion of the unwanted dopants out of the substrate can be optimized. Furthermore, a surface cleaning effect occurs.

Advantageously, the first impurity type can be a p-type impurity and the second impurity type an n-type impurity. The n-type semiconductor on insulator layer substrate plays an important role in opto-electronic applications, but starting substrates of the n-type have a lower quality, in particular concerning COP defects, than corresponding p-type substrates. With the method according to the invention, it is thus possible to obtain a desired substrate with improved properties concerning defect density.

Preferably, the first semiconductor substrate is one of a silicon, germanium, gallium, arsenide, SiC substrate. Advantageously, the second substrate can be one of silicon, germanium, gallium arsenide, quartz, SiC, preferably comprising a dielectric layer on one of its main surfaces.

Advantageously, the first impurity density can be in the range of $0.5 \cdot 10^{16}$ to $5 \cdot 10^{16}$ atoms/cm³ and the second impurity density and the third impurity density are of the same order, in particular in the range of $0.5 \cdot 10^{14}$ to $5 \cdot 10^{14}$ atoms/cm³. Thus; with this method starting for instance with a p substrate, a final dopant concentration of the n- type can be obtained in the final substrate.

According to a variant, at least one further layer can be grown on the layer provided during step d) with a fourth impurity density, in particular of the first impurity type. Thus, a layer structure with a dopant concentration of the p++ type (impurity concentration of the order of 10^{18}) can be provided on the n- layer, which could be used in a CIS image sensor.

In the following, an advantageous embodiment of the invention will be described in relation to the enclosed Figures.

Figures 1a – 1i illustrate an embodiment of the method according to the invention, and

Figures 2a and 2b illustrate the dopant profile of a first substrate and the one achieved for the semiconductor on insulator substrate with the additional layer fabricated according to the invention.

According to step a) of the inventive method (illustrated in Figure 1a), a first semiconductor substrate 1 with a first impurity density of a first impurity type is provided. This substrate can be a silicon, germanium, gallium arsenide or SiC wafer, e.g. a 200mm or 300mm type wafer. According to a variant, the semiconductor substrate could also be a base substrate of any material with a semiconductor layer provided thereon.

In this embodiment, the semiconductor substrate 1 is a lowly doped substrate, typically with a dopant concentration or impurity density in the order of $0.5 \cdot 10^{16}$ to $5 \cdot 10^{16}$ atoms/cm³. Here, the semiconductor substrate 1 is a p-type impurity doped silicon substrate, for instance using boron as an impurity atom. P-type substrates have the advantage that they have good crystalline properties and, in particular, can be provided COP defect free.

Figure 1b illustrates step b) of the inventive method. This step consists in providing a thermal treatment of the semiconductor substrate 1 to reduce the first impurity density in a modified layer 3 adjacent to one main surface of the first semiconductor substrate 1. The thermal treatment is carried out under a neutral atmosphere, for instance under helium or argon, such that the impurity atoms can diffuse out of the substrate as illustrated by the arrows in Figure 1b. Depending on the conditions of the thermal treatment step, the temperature can go up to 1200°C, with a duration of the treatment of up to several hours, a depleted layer 3 of a thickness in a range of about 100nm to 300nm is achieved.

Figure 2a illustrates – only schematically – the dopant concentration profile achieved for the structure illustrated in Figure 1b. Before the thermal treatment, the substrate 1 has a flat p-type dopant profile as illustrated by the dotted line 31.

After the thermal treatment, the dopant concentration 33 illustrated by a plain line is achieved. Close to the surface of the substrate 1, a depleted region can be observed which defines the modified layer 3. This layer typically has a thickness of 100nm to 300nm depending on the thermal budget.

Subsequently, as illustrated in Figure 1c, a dielectric layer 5, for instance silicon dioxide in the case of a silicon semiconductor substrate 1, is provided on the semiconductor substrate 1. This layer can be achieved by thermal oxidation or deposition. The silicon oxide layer 5 typically has a thickness of 200nm to 400nm, but an ultra thin oxide layer of about 10nm or a composite dielectric layer with a nitride and an oxide can also be considered.

Subsequently, as illustrated in Figure 1d, a predetermined splitting area 7 is formed inside the modified layer 3 with the reduced impurity density. The predetermined splitting area 7 can be achieved by implanting atomic species and/or ions 9 through the dielectric layer 5 using, for instance helium and/or hydrogen ions.

Furthermore, a second substrate 11, for instance a silicon wafer, a germanium wafer, a gallium arsenide, a SiC wafer or a transparent substrate such as a quartz or glass substrate, with or without an additional dielectric layer (not shown) on its surface 13 are provided (see Figure 1e). The second substrate 11, can also be a p-type or n-type doped substrate.

The next step, illustrated in Figure 1f, consists of attaching, here by bonding, the first semiconductor substrate 1 to the second substrate 11 such that the dielectric layer 5 and the modified layer 3 are sandwiched between the substrates 1 and 11. By subjecting the bonded structure 13 to a thermal and/or mechanical treatment, for instance a thermal anneal at a temperature of about 500 - 600°C, detachment occurs at the predetermined splitting area 7 and thereby, at least a part 15 of the modified layer 3 together with the dielectric 5, is transferred onto the second substrate 11. This modified second substrate 17 is illustrated in Figure 1g and the remainder 19 of the first semiconductor substrate 1 is illustrated in Figure 1h. As the predetermined splitting area 7 was inside the modified layer 3, the remainder

19 still comprises a remaining part 21 of the modified layer 3 with the reduced first impurity density.

The remaining part 19 of the first semiconductor substrate 1 can be recycled, for instance comprising a cleaning and/or a polishing step and be reused either as a new first substrate or as a second substrate. Depending on the thickness of the remaining part 21 of the modified layer with reduced impurity density, the recycled substrate 19 may not be subjected to the thermal treatment illustrated in Figure 1b again, but the subsequent fabrication run will directly start with the step of providing a dielectric layer 5 on the layer 19/3 as illustrated in Figure 1c. In case the thickness of layer 19 is not sufficient for a new fabrication run, the subsequent run will start with the thermal treatment step of the process as illustrated in Figure 1b. By doing so, not only the use of the semiconductor material is optimized by reusing one donor substrate for a plurality of fabrication runs, but also the amount of process steps can be optimized. Indeed, one thermal treatment step to reduce the impurity density in the first semiconductor substrate 1 can thus be sufficient for a plurality of fabrication sequences as illustrated in Figure 1.

As illustrated in Figure 1i, a further layer 23 is then provided on the transferred layer 15 of the modified second substrate 17 according to step d) of claim 1. This layer 23 is either hetero- or homoepitaxially, but preferably homoepitaxially grown on the transferred layer 15. Its thickness is typically of the order of 1 to 6 μm .

During the growth, the epitaxial layer 23 is subjected to a dopant treatment using n-type impurity atoms, for instance phosphorous atoms, thus of the opposite type compared to the first substrate 1. By diffusion or auto-doping, the transferred layer 15 will also become doped by the second impurity type. According to a variant, the dopant treatment could also be carried out after the growth of the epitaxial layer 23. Preferably, the growth and doping step are carried out in one and the same tool, for instance an epi-reactor.

Figure 2b illustrates – only schematically - the corresponding dopant profile of the final substrate 25. The second substrate can have any dopant structure, e.g. n or p, but is preferably not doped. Furthermore, the buried oxide layer 5, is also not

doped. Due to the auto-doping and/or diffusion effects, an n-type dopant concentration of about 10^{14} at/cm³ is observed in the transferred layer 15. Thus, the previously p-type doped layer now has an n-type doping property. Finally layer 23 also has a dopant concentration of about 10^{14} at/cm³ and remains n-type.

According to a variant of the inventive embodiment, an additional thermal treatment step can be carried out between the steps illustrated in Figures 1g and 1i to further reduce the p-type dopant concentration in the transferred layer 15. Again, this thermal treatment is carried out under a neutral atmosphere, for instance helium or argon.

Without departing from the scope of the invention, instead of starting with a p-type substrate 1 to finally achieve an n-type doped final substrate 25, one can of course also start with an n-type starting material to achieve a final p-type substrate comprising the epitaxial layer.

According to a further variant of the inventive embodiment which can be combined with any embodiment or variant alone or in combination, at least one further layer is grown on the layer 23 with a fourth impurity density. The fourth impurity density can, for instance, be of a p++ type, thus with an impurity concentration of the order of 10^{18} at/cm³. Thus, a substrate like needed in optoelectronic applications, such as in a BCIS image sensor, can be formed.

With this method, it is possible to prevent contamination of a Smart Cut™ p-type fabrication line by n-type dopants (phosphorous) and, at the same time, high quality n-type SOI substrates with an epitaxial layer for use in opto-electronics (BISC substrates) can be achieved, as one starts with the better quality p-type substrates.

CLAIMS

1. Method for fabricating a semiconductor substrate, in particular a semiconductor on insulator, substrate comprising the steps of:
 - a. providing a first semiconductor substrate with a first impurity density of a first impurity type,
 - b. subjecting the first semiconductor substrate to a first thermal treatment to thereby reduce the first impurity density in a modified layer adjacent one main surface of the first semiconductor substrate,
 - c. transferring at least partially the modified layer with the reduced first impurity density onto a second substrate, to thereby obtain a modified second substrate, and
 - d. providing a layer on a transferred layer of the modified second substrate, in particular by epitaxial growth, with a second impurity density of a second impurity type different to the first impurity type.
2. Method according to claim 1, wherein step d) is carried out such that the transferred layer has a third impurity density of the second impurity type.
3. Method according to claim 1 or 2, further comprising an additional step e) of subjecting the modified second substrate to a second thermal treatment after step c) and before step d).
4. Method according to one of claims 1 to 3, wherein step c) comprises:
 - f. creating a predetermined splitting area inside the first semiconductor substrate, preferably such that the predetermined splitting area is inside the modified layer with the reduced impurity density,
 - g. attaching, preferably by bonding, the first semiconductor substrate to the second semiconductor substrate to sandwich the reduced first impurity density layer therebetween, and

- h. subjecting the bonded structure to a third thermal and/or mechanical treatment such that detachment occurs at the predetermined splitting area.
- 5. Method according to one of claims 1 to 4, further comprising providing a dielectric layer (5) on the modified layer (3) with reduced impurity density.
 - 6. Method according to one of claims 1 to 5, wherein the remaining part of the first semiconductor substrate obtained during step c) is reused as a new first semiconductor substrate in a subsequent semiconductor substrate fabricating process comprising at least steps c) and d).
 - 7. Method according to claim 6, wherein step b) is carried out such that steps c) and d) can be carried out at least two times without repeating step b).
 - 8. Method according to one of claims 1 to 7, wherein the remaining part of the first semiconductor substrate obtained during step c) is reused as a new semiconductor substrate in a subsequent semiconductor substrate fabricating process comprising at least steps c) and d).
 - 9. Method according to one of claims 1 to 8, wherein the first and second thermal treatment are carried out in a neutral atmosphere, in particular a He or Ar atmosphere.
 - 10. Method according to one of claims 1 to 9, wherein the first impurity type is a p-type impurity and the second impurity type is an n-type impurity.
 - 11. Method according to one of claims 1 to 10, wherein the first semiconductor substrate is one of a Si, Ge, GaAs, SiC substrate.
 - 12. Method according to one of claims 1 to 11, wherein the second substrate is one of Si, Ge, GaAs, quartz, SiC, in particular comprising a dielectric layer on one of its main surfaces.

13. Method according to one of claims 1 to 12, wherein the first impurity density is in the range of $0.5 \cdot 10^{16}$ to $5 \cdot 10^{16}$ atoms/cm³ and the second impurity density and the third impurity density are of the same order, in particular in the range of $0.5 \cdot 10^{14}$ to $5 \cdot 10^{14}$ atoms/cm³.
14. Method according to one of claims 1 to 13, wherein at least one additional layer with a fourth impurity density is provided on the layer with the third impurity density.