Method for Transferring a Layer from a Donor Substrate onto a Handle Substrate

The invention relates to a method for transferring a layer from a donor substrate onto a handle substrate and for reclaiming the surface of the donor substrate for reuse.

The so-called Smart Cut™ process, illustrated in Figure 1 provides high quality silicon on insulator (SOI) substrates. During this process (Figure 1a), two substrates, called a handle substrate 101 and a donor substrate 103, usually Silicon wafers, undergo a certain number of process steps to transfer a layer with a given thickness of the donor substrate 103 onto the handle substrate 101. During the process, the donor substrate 103 is typically oxidized 105 to later on form the buried oxide layer (BOX) of the SOI structure, and an ion implantation step, during which ions like hydrogen or rare gas ions (He, Ar, ..) are implanted into the donor substrate 103, is applied to form a predetermined splitting area 107 defining the to-be-transferred layer. Subsequently (Figure 1b), the source substrate 103 is attached to the handle substrate 101, in particular via bonding taking advantage of Van der Waal's forces, to obtain a source-handle compound 109. Upon a mechanical and/or thermal treatment, a detachment of a semiconductor layer 111 together with the buried oxide layer 113 occurs at the predetermined splitting area 107 so that the two layers are transferred onto the handle substrate 101 to obtain the desired silicon on insulator structure 115 (Figure 1c). The thickness of the layer 111 is determined by the energy of the implanted ions.

The remaining part 117 of the donor substrate 101, also called the negative, can be recycled and again used in the Smart Cut™ type process as a new donor or handle substrate. The Smart Cut™ type SOI fabrication process has a significant economic advantage due to this recycling process. Indeed, the process provides an optimized use of the raw material for instance silicon wafers.

The negative 117 (Figure 1c) has a characteristic topography representing protruding residues 119a and 119b in an edge region, as illustrated in Figure 1, which corresponds to a region where no layer transfer occurred due to the chamfered shape of the edge of the initial wafers 103 and/or 101. The surface of the negative

117 between the protruding residues 119a and 119b has a first inner region 121 at which detachment occurred to provide the transferred layer 111 on the handle substrate 109 and which has a rather rough surface typically close to 60 – 70 Å RMS as measured by atomic force microscopy (AFM), which is to be compared to 1 – 3 Å for standard Silicon wafer. The edge of the remainder 117 with the protruding residues 119a and 119b actually has a chamfered shape and furthermore comprises a step-like structure 123 seen from the internal region 121 comprising the remaining part of the buried oxide layer 125 and the non-transferred silicon 127 over the remaining part of the ion implanted predetermined splitting area 129. The edge 131 and the backside 133 of the negative 117 are, by the way, also covered by the oxide.

The step 123 of the negative 117 typically has a thickness of about 100-10000 Å of silicon, mostly between 1000 to 3000 Å, and 100 to 10000 Å of silicon oxide and has a width w in the lateral direction of the order of 0.5 – 3 mm.

Prior to the reuse of the negative 117 as donor substrate 103 or handle substrate 101, the surface roughness of the inner region 121 needs to be reduced and the protruding residual topography 119a & 119b needs to be removed. The removal needs to be complete as any remaining protruding material can create particle contamination when during a thermal treatment an exfoliation in the chamfered region occurs due the presence of the remaining ion implanted region 129. Methods to do so are, for example, known from EP 1 156 531 A1 and US 7,402,520 B2. Typically, the following process is applied to get rid of the protruding residual topography: The reclaiming process of negative 117 starts with a de-oxidation step to remove the oxide layer 125 on top of the protruding residual topography on the edge of the remainder 117 as well as on the side 131 and on its backside 133. The de-oxidation can, for example, be carried out using a HF bath, wherein the acid consumes the oxide layer 125, 131 and 133. Subsequently, a first polishing step of the edge region of substrate 1 is carried out to at least partially remove the protruding silicon part 127 on the edge. Then a double-sided polishing (DSP) step is carried out to improve the surface roughness in the interior region 121 but also to further remove the step 123 in the direction of the protruding residual topography 119a and 119b, but also to remove residues remaining form the ion implantation. Finally, to obtain a suitable surface roughness on the front surface of the remainder 117, a chemical mechanical polishing step (CMP) is carried out.

Even though, it is possible to obtain a recycled substrate with the described reclaiming process and which can be reused in the Smart Cut™ process, embodiments of the present invention seek to provide an improved and more economic reclaiming process that may no longer need the double-sided polishing step to reclaim the remainder of the donor substrate. Indeed, the DSP process step has the major disadvantage that, during polishing, up to 10 µm (5 µm on each side of the substrate) of material are removed to get rid of the protruding residual topography 119a and 119b.

According to an aspect of the present invention, there is provided a method for transferring a layer from a donor substrate onto a handle substrate and for reclaiming a surface of the donor substrate for reuse, with the steps of: a) providing said donor substrate, in particular a semiconductor substrate, and said handle substrate each with chamfered regions, b) forming a predetermined splitting area at about a depth h inside the donor substrate, c) attaching, in particular by bonding, the donor and the handle substrates to obtain a donor-handle compound, wherein no attaching occurs between the two substrates in the chamfered regions of the donor and handle substrates, then d) etching the chamfered regions such that at least an etched layer of about at least a predetermined thickness h is removed from the donor substrate in the chamfered regions where no attaching occurred, then e) detaching a remainder of the donor substrate from the donor-handle compound wherein detachment occurs at the predetermined splitting area, and f) reusing the remainder of the donor substrate, in particular after a surface treatment step, wherein the donor substrate comprises a dielectric layer, and wherein the method comprises a step g) carried out between steps c) and d) which consists in removing the dielectric layer from the donor substrate at least in the chamfered region of the donor substrate but not in an attached region of the donor substrate.

Thus, unlike in the process of the prior art, the remainder of the donor substrate may no longer present a protruding portion 119a, 119b as illustrated in Figure 1, as the chamfered area where no attachment occurs between the two attached substrates is removed prior to the detachment. By the fact that, no longer any protruding regions are present at the surface of the remainder of the donor substrate, there is no need

for carrying out the edge removal step and the double-sided polishing step which were mandatory in the prior art to get rid of the protruding portion. As a consequence, the reclaiming of the remainder of the donor substrate can be carried out in a much simpler way not needing expensive additional tools to carry out the edge polishing and the double-sided polishing process steps. At the same time, due

to the suppression of the double-sided polishing step, the initial geometry of the donor substrates can be kept even if one donor substrate is used several times in a process as described above. In addition, due to the fact that the implanted region in the chamfered region is removed during step d), the quality of the obtained substrates may also be improved as the risk of creation of particles during a raise in temperature leading to a partial removal of the chamfered region, can be reduced.

In example embodiments, even in the presence of a dielectric used to form a semiconductor on insulator substrate with the mentioned process, it is still possible to achieve the advantages of the method as, not only the chamfered region of the donor substrate itself but also of its dielectric layer, is removed prior to detaching.

It has to be pointed out that the removal step to remove the dielectric layer does not represent an additional step which has to be carried out. Indeed, in the prior art, the dielectric layer is also removed during reclaiming. Thus, compared to the prior art, step g) is simply moved from after detachment to prior to detachment.

According to a variant, the handle substrate can comprise a dielectric layer. In this case, the dielectric layer is provided by the handle substrate to form a semiconductor on insulator substrate. This variant has the advantage that one only has to remove the material of the substrate in step d) to achieve the advantages of the invention, as no additional dielectric layer is provided on the donor substrate. Thus, in this variant, less process steps are necessary compared to the variant which provides the dielectric via the donor substrate.

Advantageously, the dielectric layer can be an oxide, in particular a silicon oxide. This oxide layer can be provided either by a thermal process or by deposition. Advantageously, steps e) and/or g) can be a wet or dry etching step. This is a more economic material removal step than the edge polishing and double-sided polished step as used in the prior art.

Preferably, steps e) and g) can be performed using a non-selective and/or isotropic etching solution. Using the non-selective etching process, both the dielectric layer and the underlying part of the donor substrate, for instance a semiconductor material, can be removed in one step. By using an isotropic etching solution, the process is furthermore simplified as varying etching rates, depending on the crystallographic directions which are different in the chamfered region compared to the rest of the substrate, do not have to be taken into account. This simplifies the control of the process.

The dielectric material removal step, independent of whether the dielectric layer is removed from the donor and/or the handle substrate (in case a dielectric is also present on the handle substrate), does not have an impact on the quality of the buried dielectric layer as this one is sandwiched between donor and handle substrate.

Advantageously, during step d), a layer with a thickness of about 100 Å – 10,000 Å, in particular 1000 – 3000 Å, can be removed in the non-attached region of the donor substrate. Compared to the double-sided polishing step mandatory in the prior art during which a large amount of material, namely in the order of 5 µm on each side, had to be removed to get rid of the protruding portions, the material removal in the process according the invention can be less so that one donor substrate can be reused more often, for instance, more than 10 times, compared to the prior art process. This is also made possible by the fact that the reclaimed donor substrate remains within the semi-standard concerning the substrate dimensions.

Preferably, steps d) and/or g) can be carried out at a temperature of less than 500°C, preferably at less than 350°C. Thus, the whole process until detachment is carried out at low temperature so that no detachment can occur in the non-attached regions which could lead to unwanted particle contamination of the final product.

According to a preferred embodiment, the surface treatment step can, at most, comprise a polishing step, in particular a CMP polishing and a cleaning step before and/or after the polishing step. Thus, compared to the prior art, a greatly simplified reclaiming process can be carried out. The polishing step is used to get the desired surface quality of the reclaimed remainder of the donor substrate, typically a mirror

polished quality, and the cleaning steps, as known in the art, make the reclaimed donor substrate ready for reuse. Thus, instead of a three-level reclaiming process: i) edge polishing, ii) double-sided polishing, iii) mirror polishing plus the various cleaning steps, the invention provides the possibility to carry out the reclaiming process with only one simple mirror polishing step.

In this context, the term "about the thickness h" used in claim 1 relates to thickness that are such that the remainder can be planarised using only a CMP process. This means that a layer is removed in step d) of claim 1 that has a thickness of at least h minus about 50nm. This would lead to a protruding region in the remainder of the donor substrate with a height of about 50nm which can be dealt with by a simple CMP polishing step.

Advantageously, during CMP polishing, a layer of less than 3 µm, preferably less than 1 µm, can be removed from the surface where detachment occurred. As mentioned above, this limited material removal brings the advantage that one donor substrate can be reused more often, in particular, more than 10 times, in the layer transfer process.

Advantageous embodiments will be described in combination with the enclosed Figures.

Figures 1a to 1c illustrates a prior art layer transfer process according to the SmartCut™ technology,

Figures 2a to 2d illustrate a first embodiment of the inventive method,

Figures 3a to 3e illustrate a second embodiment of the inventive method, and

Figures 4a to 4d illustrate a third embodiment of the inventive method.

Figures 2a – 2d illustrate a first embodiment of the inventive method for transferring a layer from a donor substrate onto a handle substrate. Figure 2a illustrates the source-handle compound 109, as already illustrated in Figure 1b. This source-handle compound 109 has all the properties as already described above in the

introduction and is therefore not described in detail again, but reference is made to Figure 1.

It should nevertheless be mentioned that the handle substrate 101 can be any suitable handle substrate, in particular a silicon wafer, but also a glass or quartz type substrate. The donor substrate 103 can be a semiconductor substrate, in particular one out of a silicon, a silicon carbide, a silicon germanium, a gallium nitride or a germanium substrate and the isolating dielectric layer 105 can be one out of silicon dioxide, silicon nitride, silicon oxynitride or Al_2O_3, etc.

In the following, the inventive method will be described, without being limited to this particular choice, to a handle substrate 101 being a silicon wafer, a donor substrate 103 being a silicon wafer and the dielectric layer 105 being a silicon dioxide.

Figure 2b illustrates the source-handle compound 201 obtained after an etching step during which the dielectric layer 105 has been removed from the back side 203, the side 205 but also the chamfered regions 207 and 209 of the donor substrate. A dielectric layer 105' remains sandwiched between the donor substrate 103 and the handle substrate 101 and forms the future buried oxide layer.

In this embodiment, the material removal is achieved with an etching step. The etching can be a dry or a wet etching suitable to remove the dielectric oxide layer which typically has a thickness of up to 1000 nm, but typically has a thickness of 10 – 200 nm.

Subsequently, as illustrated in Figure 2c, an additional etching step is carried out to remove the silicon present in the chamfered region 207' and 209'. The etching step can again be a wet or dry etching and is preferably an isotropic etching for instance using a wet etch with HF/HNO_3 or a dry etch using a plasma. According to a variant the dielectric etching and the semiconductor etching are carried out using the same process.

The etching is carried out such that material is removed from the chamfered region 207' and 209' at least of the donor substrate 103 and such that the removed layer has a thickness h_1 corresponding to the depth h of the predetermined splitting area

107. Typically the material removal not only occurs in the chamfered region but also on the side and on the back side of the donor substrate 103 and also in the chamfered region 211 and 213 of the handle substrate 101.

By doing so, the ion implanted region 129, present in the chamfered part 207 and 209 illustrated in Figure 2b, of the donor substrate 103 is removed.

The next step consists in a detachment step, the result of which is illustrated in Figure 2d and which is carried out in the same way as described in the introduction, thus either using mechanical and/or thermal energy. After detachment a semiconductor on insulator, here silicon on insulator substrate 215, as illustrated on the right hand side of Figure 2d, is obtained. This structure 215 comprises the handle substrate 101, the transferred oxide layer 105' and the transferred silicon layer 111 from the donor substrate 103. Due to the etching process, the substrate 215 furthermore comprises a step-like shoulder 217 in the chamfered edge regions 211 and 213 of the handle substrate 101 which makes the geometry of semiconductor on insulator substrate 215 slightly different compared to the one illustrated in Figure 1c.

The effect of the inventive method is even more visible on the remainder 219 of the donor substrate 103 illustrated on the left hand side of Figure 2d. The remainder of the donor substrate 219, according to the invention, no longer has a protruding portion in its edge region which is in complete contrast to the structure 117 according to the prior art illustrated in the left hand side of Figure 1c in the prior art.

The surface part 221 where detachment occurred has a rather rough surface, with roughness values close to 60 - 70Å like in the prior art. However, due to the fact that the protruding portion is not present, the surface roughness can be improved by a simple CMP polishing process during which less than 3 µm, preferably less than 1 µm, or even only about 50nm, of material is removed from the surface to obtain the desired surface quality for reuse of the reclaimed remainder 219.

The chemical/mechanical polishing step can be accompanied by standard cleaning processes as in the prior art.

Compared to the prior art, the method according to the first embodiment has the advantage that, after detachment, no protruding portions are present in the edge regions, which is in complete contrast with the prior art, see reference numerals 119a, 119b in Figure 1. As a consequence, the reclaiming process to recondition the remainder of the donor substrate 219 such that it can be reduced is greatly simplified. No edge polishing and no double-sided polishing are necessary anymore and a simple CMP process is sufficient to obtain the desired surface quality properties, eventually accompanied by one or two cleaning steps. Thus, the recycling process is not only cheaper to carry, as less equipment is necessary for the process, but also one donor substrate can be reused more often. Whereas, typically 10 µm of material had to be removed in the prior art process, the inventive process can be carried out with a greatly reduced material removal of the order of less than 3 µm, typically 0.5 – 1 µm. It is even possible to carry out the reclaiming process by only removing about 50nm from the surface 221. Thus, one donor substrate 103 can be recycled more often than in the prior art, namely about at least 10 times. Due to the fact that no DSP is necessary, also the geometry of the initial substrate can be kept. Besides, another important advantage is, that the creation of particles during step e), i.e. thermal treatment leading to the detachment or any subsequent thermal treatment step can be prevented or at least reduced as, in the chamfered region, the remaining ion implanted part is removed so that it cannot explode away during a subsequent thermal treatment and thus the creation of undesired particles can be reduced or even prevented.

Figures 3a – 3e illustrate a second embodiment of the inventive method for transferring a layer of a donor substrate 103 onto a handle substrate 101. Figure 3a again illustrates the source-handle compound 109, the description thereof is not repeated again but incorporated herewith by reference to the description of Figure 2a. The same is valid for Figure 3b, illustrating the resulting structure 201 after the dielectric material removal step.

The difference between the first embodiment and the second embodiment is that, during the etching of the chamfered region 207'' and 209'' of the donor substrate 103, the material removal goes beyond the depth of the predetermined splitting area 107, 129, as illustrated in Figure 3c, by reference numeral h2. Again, the predetermined splitting area 107 is still present within the donor substrate 103. As a

consequence of the longer etching process, also the material removal in the chamfered region 211' and 213' of the handle substrate 101 is of the order of h2.

Compared to the first embodiment, the additional material removal has the advantage that it is ensured that all implanted areas 129 present in the chamfered region 207 and 209 are removed.

After the detachment step, the semiconductor on insulator substrate 301, as illustrated on the right hand side of Figure 2d, is obtained which essentially corresponds to the one 215 illustrated on the right hand side of Figure 2d. However, the step-like region 303 at the transition between the chamfered region 211' and 213' and the buried oxide layer 105' is higher (h2) than in the semiconductor on insulator structure 215 of Figure 2d.

Unlike the remainder 217 illustrated in Figure 2d, the remainder of the donor substrate 305 in this embodiment also has a step-like shoulder 307 with a step height h2. However, like in the first embodiment, the surface 309 at which detachment occurred still carries defects due to the ion implantation and thus needs to be polished. In the second embodiment, the polishing step is carried out such that the step-like structure 307 is removed so that a ready to reuse donor substrate 311, as illustrated in Figure 3e, is obtained. This substrate 311 is again flat, except for the chamfered region, which is like in the original substrate 103, except for a reduced thickness.

With the second embodiment, the same advantages as can be achieved like with the first embodiment.

According to a variant of the invention, instead of providing a semiconductor on insulator substrate, the process could be carried out without an intervening dielectric layer, which is called a direct silicon bonding process. In this case, the first and second embodiments could be carried out without the step of removing the dielectric 105, as illustrated in Figures 2b and 3b.

Figures 4a – 4d illustrate a third embodiment of the invention. This embodiment is slightly different compared to the first and second embodiments as, here, the

dielectric layer is provided on the handle substrate side and the donor substrate is a bare semiconductor wafer, for instance a silicon wafer. The materials that can be used in this embodiment correspond to the ones of the first and second embodiment.

The left side of Figure 4a illustrates the donor substrate 401 with a predetermined splitting area 403 and the right side the handle substrate 405, which in this case also comprises a dielectric layer, for instance silicon oxide, 407.

Figure 4b illustrates the source handle compound 409 achieved by bonding the donor and the handle substrate 401 and 405. Like in the first and second embodiment on the surface side where bonding occurred a non attached region 411 and 413 can be observed which is due to the chamfered edge region of both substrates.

Subsequently, and as illustrated in Figure 4c, a etching step is carried out to remove a layer of thickness h_1 corresponding to the depth h of the predetermined splitting are 403 is removed in the non attached edge regions 411' and 413'. Thus like in the first and second embodiment, the ion implanted region 129 in the edge region of the donor substrate 401 is removed by this step. As the donor substrate 401 is not covered by the dielectric layer, which is in contrast to the first and second embodiment, no oxide removal step is necessary in this embodiment.

After detachment, achieved by a thermal and/or mechanical treatment, a SOI substrate 415 is obtained comprising a transferred layer 417 and a buried oxide layer 419 still part of the original dielectric layer 407 covering the handle substrate 405. Eventually a deoxidation step could be carried out to remove the dielectric layer 407 except for the buried part 415 to obtain a SOI substrate as illustrated in Figures 2d or 3d.

The remainder 421 of the original donor substrate 401 has the same structure than the one illustrated in Figure 2d. A simple CMP polishing process is sufficient to remove the defects on the surface 423 where detachment occurred.

Finally, according to a variant, the material removal step illustrated in Figure 4c, could also be carried out such that a thickness h_2 is removed which is larger than the depth h of the predetermined splitting area 403, just like in the second embodiment.

According to a variant the first till third embodiments can also be carried out without the presence of a buried oxide layer 105'. In the so called direct silicon bonding technology two Si wafers typically one with a 100 and the other one with a 110 surface are bonded together. In this case the process described are carried out in the same way without however the step of removing the oxide by etching. It should furthermore be mentioned that by CMP a remaining protruding portion of about 50nm, which could be present in the edge region in case the material removal did not go up until h or beyond, can still be removed.

In the following practical examples according to the invention will be described.

Example one according to the invention: a Silicon on Insulator substrate with a buried thermal oxide of thickness 145 nm and a transferred layer of thickness 250nm is achieved using an etching process of the source handle substrate as illustrated in Figure 2b. In this example the oxide is etched using HF and then the Si is etched using HF/HNO_3 such that h_1 = h = 250nm +/- 5%. The remainder of the donor substrate is recycled using a CMP process removing a layer with thickness of 0.5µm. In this example a two step selective etching is carried out: first the HF removes the oxide but does not etch Si, and the second bath using HF/HNO3 eventually buffered using CH_3COOH acid etches the silicon.

Example two according to the invention: a Silicon on Insulator substrate with a buried thermal oxide of thickness 145 nm and a transferred layer of thickness 300nm is achieved using an etching process with $HF/H_2O_2/H_2O$ and h_1 = 250nm, with h being 300nm. The recycling of the remainder is carried out by an EP and CMP step. In this example the HF/ H_2O_2 bath is not selective and both layers the oxide and the silicon can be etched in one step. Edge polishing is performed to get rid of any potential residue of the implanted layer on the edge since material removal did not go up until h or beyond (h_1 ~ h –50nm), but the remaining 50 nm can also be removed with a CMP step and no EP polishing.

Example three according to the invention: a Silicon on Insulator substrate with a buried thermal oxide of 10nm thickness and a transferred layer of 250nm is achieved using a plasma (dry) etch such that $h_1 = h = 250nm+/- 5\%$. During the dry etch, a first plasma based on CF_4 or CHF_3 etches the oxide and then a second plasma on the basis of SF_6 etches the silicon. In this case one of the two substrates, preferably the donor substrate, has one of its main surfaces, called the back surface, on a substrate holder which prevents etching of the back side. In this case the reclaiming of the remainder of the donor substrate comprises an additional deoxidation step to remove the oxide from the back side plus the CMP step polishing the front surface and removing about 1µm of Silicon.

Example four according to the invention: a Silicon on Insulator substrate with a 145nm buried insulator layer comprising SiO_xN_y and one or more SiO_2 layers, etched using HF and H_3PO_4 and then HF/HNO3 such that $h_1 = h = 250nm+/- 5\%$.

Claims

1. Method for transferring a layer from a donor substrate onto a handle substrate and for reclaiming a surface of the donor substrate for reuse, with the steps of:

   a) providing said donor substrate, in particular a semiconductor substrate, and said handle substrate each with chamfered regions,
   b) forming a predetermined splitting area at about a depth h inside the donor substrate,
   c) attaching, in particular by bonding, the donor and the handle substrates to obtain a donor-handle compound, wherein no attaching occurs between the two substrates in the chamfered regions of the donor and handle substrates, then
   d) etching the chamfered regions such that at least an etched layer of about at least a predetermined thickness h is removed from the donor substrate in the chamfered regions where no attaching occurred, then
   e) detaching a remainder of the donor substrate from the donor-handle compound wherein detachment occurs at the predetermined splitting area, and
   f) reusing the remainder of the donor substrate, in particular after a surface treatment step,

   wherein the donor substrate comprises a dielectric layer, and wherein the method comprises a step g) carried out between steps c) and d) which consists in removing the dielectric layer from the donor substrate at least in the chamfered region of the donor substrate but not in an attached region of the donor substrate.

2. Method according to claim 1, wherein the handle substrate comprises a dielectric layer.

3. Method according to claim 1 or 2, wherein the dielectric layer is an oxide, in particular a silicon oxide.

4. Method according to one of claims 1 to 3, wherein step e) and/or g) is a wet or dry etching step.

5. Method according to claim 4, wherein step e) and g) are performed using a non selective and/or isotropic etching solution.

6. Method according to one of claims 1 to 5, wherein during step d) a layer with a thickness of about 100 Å to 10.000 Å, in particular 1000 Å to 3000 Å, is removed in the non attached region of the donor substrate.

7. Method according to one of claims 1 to 6, wherein step d) and/or g) are carried out at a temperature of less than 500°C, preferably at less than 350°C.

8. Method according to one of claims 1 to 7, wherein the surface treatment step at most comprises a polishing step, in particular a CMP polishing, and a cleaning step before and/or after the polishing step.

9. Method according to claim 8, wherein during CMP polishing a layer of less than 3µm, preferably less than 1µm, is removed from the surface where detachment occurred.