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(71) Applicant (for all designated States except US): **S.O.I. TEC SILICON ON INSULATOR TECHNOLOGIES** [FR/FR]; Parc Technologique des Fontaines, Chemin des Franques, F-38190 Bernin (FR).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **PERSONNIC, Sébastien** [FR/FR]; 65 rue Bizanet, F-38000 Grenoble (FR). **BOURDELLE, Konstantin** [FR/FR]; 22 rue du Luiset, F-38920 Crolles (FR).

(74) Agent: **DESORMIERE, Pierre-Louis**; Cabinet BEAU DE LOMENIE, 158 rue de l'Université, F-75340 Paris Cedex 07 (FR).

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(54) Title: LAYER TRANSFER WITH REDUCTION OF POST-FRACTURE ROUGHNESS

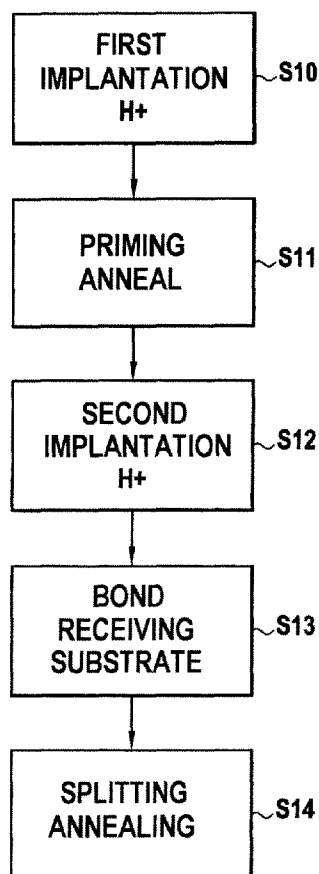


FIG.4

(57) Abstract: The invention provides a method of transferring a layer of a donor substrate onto a receiving substrate, the method comprising : a first step (S10) for hydrogen ions into the donor substrate intended to form a layer of microcavities or platelets; a second step (S12) of implanting ions; a step (S13) for bonding the face of the donor substrate with a face of the receiving substrate; a step (S14) for detachment to cause splitting at the layer of microcavities or platelets formed in the donor substrate. The method further comprises, between the two implantation steps, a step (S11) for priming anneal heat treatment carried out at a temperature in the range 300°C to 700°C and for a duration that is less than 10% of the duration necessary to cause splitting at the layer of microcavities or platelets formed in the donor substrate at the temperature employed during said priming anneal heat treatment.

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LAYER TRANSFER WITH REDUCTION OF POST-FRACTURE ROUGHNESS**Technical field and prior art**

The present invention relates to a method of
5 transferring a layer of a donor substrate onto a
receiving substrate used during the fabrication of
heterostructures such as SeOI (semiconductor on
insulator) structures for electronic, microelectronic,
and optoelectronic applications.

10 A well known technique for the production of
heterostructures by layer transfer is the Smart Cut™
technique. A particular implementation of the Smart Cut™
technique is described in US patent document
US-A-5 374 564 or in the article by A.J. Auberton-Hervé
15 et al entitled "Why can Smart Cut change the future of
microelectronics?", Int. Journal of High Speed
Electronics and Systems, vol 10, No1, 2000, p 131-146.
That technique employs the following steps:

a) bombarding one face of a donor substrate (formed
20 from silicon, for example) with light ions of the
hydrogen or noble gas type (for example hydrogen and/or
helium) to implant those ions in a sufficient
concentration in the substrate, the implanted zone
allowing the creation of a layer of weakness by forming
25 microcavities or platelets;

b) bringing that face of the donor substrate into
intimate contact (bonding) with a receiving substrate;
and

c) splitting annealing to cause, by a pressure and
30 crystal rearrangement effect in the microcavities or
platelets formed from the implanted species, fracture or
splitting at the implanted layer to obtain a
heterostructure resulting from transfer of the layer of
donor substrate onto the receiving substrate.

35 However, after such a transfer, the transferred
layer as well as the donor substrate both exhibit surface
roughness.

Documents US-2006/0060943 and US-2007/0037363 describe co-implantation methods, i.e. implantation of at least two different gaseous species, which methods can limit the surface roughness of the transferred layer and the donor substrate after transfer.

Document US-A-6 150 239 also describes a method of co-implanting a donor substrate in order to transfer a layer of that substrate onto a receiving substrate, which method enables detachment to be carried out at a lower temperature and post-fracture roughness to be reduced. The method described in that document principally comprises the following steps:

- implanting a donor substrate with a first gaseous species that can trap hydrogen in the substrate;
- implanting hydrogen into the donor substrate defining the layer to be transferred;
- applying heat treatment at a temperature that is lower than the detachment temperature, thereby forming microcracks in the substrate;
- bonding the donor substrate onto a receiving substrate;
- applying splitting annealing at a temperature that can cause splitting/fracture of the donor substrate at the implanted zone so as to transfer the layer of donor substrate onto the receiving substrate.

However, even with such existing solutions, the reduction in surface roughness after detachment is still limited.

Summary of the invention

The present invention aims to propose a solution that can further reduce the after-transfer (post-fracture) surface roughness present both on the transferred layer and on the donor substrate.

To this end, the invention provides a method of transferring a layer of a donor substrate onto a receiving substrate, the method comprising:

a) a first step of implanting hydrogen ions into the donor substrate with the aim of forming a layer of microcavities or platelets;

b) a second step of implantation;

5 c) a step of bonding the face of the donor substrate with the receiving substrate, for example by molecular bonding;

d) a detachment step to cause splitting at the layer of microcavities or platelets formed in the donor
10 substrate;

The method being characterized in that it further comprises, after step a) and before step b), a priming anneal heat treatment step carried out at a temperature in the range 300°C to 700°C and for a duration that is
15 less than 10% of the duration necessary to cause splitting at the layer of microcavities or platelets at the temperature employed during said priming anneal heat treatment.

The priming anneal heat treatment of the method of
20 the invention is carried out with a thermal budget (temperature and time duration corresponding to the energy supplied during the heat treatment) that is deliberately less than that necessary to cause splitting or fracture at the layer of microcavities or platelets
25 formed during step a). To this end, the temperature of the thermal budget is selected to be in the range 300°C to 700°C, which corresponds to the temperatures typically used during anneals that can cause splitting/fracture of implanted substrates, termed splitting annealing. As is
30 well known, the splitting annealing duration is determined as a function of the temperature used for that anneal. Typically, the higher the temperature of the splitting annealing, the shorter the duration thereof in order to obtain splitting/fracture at the implanted zone.
35 In general, splitting annealing is carried out at a temperature in the range 300°C to 700°C and for a duration that may be from a few seconds (for the highest

temperatures) to several tens of hours (for the lowest temperatures).

In accordance with the method of the invention, the thermal budget of the priming anneal must be defined such that less than 10% of the thermal budget that is typically necessary to cause splitting/fracture of the implanted donor substrate is applied, the duration of the thermal budget is limited to less than 10% of that necessary to accomplish said splitting/fracture at the temperature used during the priming anneal heat treatment.

Thus, by subjecting the implanted donor substrate to a prior heat treatment that is deliberately limited to a duration that is less than 10% of the normal duration for splitting annealing, the process of development/growth of defects originating from the implantation into the donor substrate is interrupted in order to limit the interaction between partially formed microcracks in a zone localized around the maximum concentration of the implanted hydrogen and the microcavities or platelets present above and below that zone.

Detachment proper is then carried out with a donor substrate already including localized microcracks. During detachment, said microcracks will preferentially develop rather than the platelets that are located above and below, thus allowing a fracture line located at the microcracks generated during the preceding heat treatment step to be produced. The surface roughness of the transferred layer and the donor substrate after detachment is thus reduced.

Detachment may be accomplished by heat treatment alone. Under such circumstances, an anneal is applied at a temperature and for a duration that can cause splitting of the donor substrate at the layer of microcavities or platelets. Detachment by splitting the donor substrate may also be accomplished by applying a mechanical separation force at the layer of microcavities or

platelets (for example by introducing a blade at this region). Further, application of a mechanical separation force may also be combined with a heat treatment.

This limitation of the duration during the priming
5 anneal heat treatment has been defined by the inventors following a study of the physical process for development/growth of defects resulting in rupture of the donor substrate during splitting annealing. This study is detailed below.

10 In one aspect of the invention, step b) corresponds to implanting hydrogen ions into the donor substrate, said second implantation step being carried out with the same implantation energy as that used in step a).

In another aspect of the invention, step b)
15 corresponds to implanting helium ions into the donor substrate, said second implantation step being carried out with an implantation energy that is determined as a function of that used in step a) so that the zone including the maximum concentration of implanted helium
20 coincides with the zone including the maximum concentration of hydrogen implanted during step a).

In yet another aspect of the invention, step b) corresponds to implanting ions into the donor substrate of at least one species that can react with the hydrogen
25 implanted during step a), said second implantation step being carried out with an implantation energy that is different from that used in step a). Implantation is carried out with an implantation energy that is preferably lower than that used in step a) such that the
30 maximum implantation peak of the reactive species is located above the maximum concentration peak of the implanted hydrogen. The species that may react with the hydrogen implanted during step a) is selected at least from fluorine, silicon, nitrogen, and carbon.

35

Brief description of the figures

The characteristics and advantages of the present

invention become more apparent from the following description made by way of non-limiting indication and with reference to the accompanying drawings, in which:

• Figure 1 shows an example of hydrogen ions into a silicon substrate;

• Figure 2 is a highly diagrammatic representation of the quality of a silicon substrate implanted with hydrogen ions after an annealing duration of less than 10% of the total splitting anneal duration;

• Figures 3A to 3E are diagrammatic sectional views showing the transfer of a layer of Si in accordance with one implementation of the invention;

• Figure 4 is a flow chart of the steps carried out in Figures 3A to 3E;

• Figures 5A to 5E are diagrammatic sectional views showing the transfer of a layer of Si in accordance with another implementation of the invention;

• Figure 6 is a flow chart of the steps carried out in Figures 5A to 5E;

• Figures 7A to 7E are diagrammatic sectional views showing the transfer of a layer of Si in accordance with another implementation of the invention;

• Figure 8 is a flow chart of the steps carried out in Figures 7A to 7E.

25

Detailed description of implementations of the invention

The present invention is applicable to any layer transfer method employing at least one step of hydrogen ions into a donor substrate to define, by a plane of weakness, a layer to be transferred, bonding the implanted donor substrate onto a receiving substrate and applying a high temperature heat treatment (splitting anneal) and/or a mechanical separation force in order to detach the layer to be transferred from the donor substrate as in the Smart CutTM technique.

35

The principle of the invention consists in encouraging the development of microcracks in a

restricted zone corresponding to the zone with the maximum concentration of implanted hydrogen, to the detriment of the platelets/microcavities located above and below this zone. Thus, by reducing the interactions
5 between these microcracks and said platelets, a final cracking line is obtained in the substrate that is localized to the restricted microcrack zone, which has the effect of reducing surface roughness following detachment.

10 Ensuring that development of the microcracks is localized in accordance with the invention is accomplished in particular by heat treatment, termed a priming anneal, that is carried out at a temperature that is normally used during splitting annealing (in the range
15 300°C to 700°C) but over a duration limited to less than 10% of that necessary to cause detachment of the substrate at that temperature. Said limitation in the duration of the priming anneal has been determined by the inventors after analyzing the physical process involved
20 during splitting annealing of an implanted substrate resulting in rupture thereof.

As a reminder, Figure 1 illustrates an example of the implantation of hydrogen in a silicon substrate 101 comprising a layer of oxide 102 (for example SiO₂).
25 During implantation, the silicon substrate 101 undergoes bombardment with H⁺ ions 100. The H⁺ ions penetrate into the substrate and are halted at a predetermined depth in the substrate 101, which means that a layer of platelet type defects 103 is created. The layer 103 forms a layer
30 of weakness that will permit fracture of the substrate to be brought about during a subsequent heat treatment. The layer 103 extends over a certain thickness in the substrate, typically over a thickness of approximately 150 nm [nanometer], and has a high concentration of
35 hydrogen at its center (hydrogen peak) and a lower concentration in its upper and lower portions.

In accordance with the Smart Cut™ technique, the implanted silicon substrate 101 then undergoes a heat treatment, termed splitting annealing, which causes growth and development of the defects created by the implanted species, finishing in causing fracture (splitting) of the substrate at the layer 103. Splitting annealing in the Smart Cut™ technique for substrates of the silicon type and more generally of a material from group IV is carried out over a range of temperatures that is typically in the range 300°C to 700°C for a predetermined duration (temperature/times duration corresponds to the thermal budget for splitting annealing). As is well known, the temperature and duration for splitting annealing are defined as a function of the implantation conditions and in particular as a function of the implantation dose.

Experimental studies carried out on silicon substrates implanted with hydrogen ions have shown that the growth of defects responsible for rupture of the substrate during splitting annealing breaks down into three phases:

1) a first phase corresponding to a very brief transitional duration which occurs from the first moments of splitting annealing, i.e. before 10% of the splitting anneal duration has passed, and at the end of which microcrack formation is already effective;

2) a second phase corresponding to a "slow" phase for growth of the microcracks formed during the first phase; and

3) a third phase corresponding to a catastrophic process of geometric coalescence of the microcracks, resulting in fracture of the substrate along a line of fracture and allowing detachment of a thin film of silicon.

The layer transfer method of the present invention was defined following identification and analysis by the inventors of the physical phenomena that are involved in

the first moments of splitting annealing. The inventors have demonstrated that from the first moments of splitting annealing (less than 10% of the time necessary to cause splitting/fracture at the temperature employed), a transitional process occurs. During this transitional process and due to the implantation, dissociation occurs of hydrogen-containing species that are temperature-unstable, resulting in the formation of a large quantity of molecular hydrogen H_2 in the material of the substrate.

10 The platelet type defects present from implantation will then absorb a large fraction of this molecular hydrogen. The gas phase formed thereby in a defect will suddenly be placed under pressure, leading to localized cracking of the substrate. At the end of this transitional process,

15 two types of defects co-exist in the substrate, namely:

- wide microcracks of several microns that nucleate in the first moments of splitting annealing by placing under pressure the platelets close to the hydrogen peak of the implanted zone (zone comprising a high density of initial defects and a high concentration of hydrogen

20 available to form gaseous H_2); and

- platelet type defects of a few tens of nanometers that are less influenced by the transitional process, i.e. that have not yet resulted in the formation of

25 microcracks, and that are mainly found below and above the hydrogen peak.

Nucleation of microcracks by placing the platelets under pressure is steered directly by the kinetics of the arrival of the gaseous hydrogen. Since a large portion

30 of the microcracks have already been formed by the end of the transitional process, the cracking path is already almost completely determined at the end of a very brief annealing duration. This duration depends on the dose and the temperature of implantation.

35 When implanting hydrogen into a monocrystalline silicon substrate with an implantation dose that is typically in the range 4×10^{16} atoms/cm² to 1×10^{17}

atoms/cm², the annealing duration necessary for the formation of the principal microcracks is less than 10% of the total duration of splitting annealing necessary to result in fracture of the substrate, regardless of the
5 envisaged annealing temperature that is within the temperature range that is normal for these circumstances, namely at any temperature in the range 300°C to 700°C.

Figure 2 is a highly diagrammatic illustration of the quality of silicon in a substrate implanted with H⁺
10 ions at the end of the transitional process, i.e. after a duration corresponding to approximately 10% of the total splitting annealing duration. The portion of the substrate represented in Figure 2 corresponds to the layer of defects resulting from implantation. As
15 explained above, the silicon present at this stage of splitting annealing already has microcracks 110 that result from the growth of certain platelets essentially located close to the center of the implantation zone (hydrogen peak) and that are placed under high pressure,
20 being subjected to large direct mutual interactions (geometric coalescence). The silicon also has platelets 111 located further from the center of the implantation zone the growth of which is only slightly influenced by the transitional process (placed under low pressure). At
25 this stage, it is already possible to mechanically propagate the fracture starting from the microcracks (for example by inserting a blade).

It should be observed that the microcracks 110 are located in a zone of small thickness compared with the
30 thickness of the implantation zone over which all of the platelets derived from implantation extends. If a final cracking path is extrapolated from the microcracks 110 (final cracking path shown in dotted lines in Figure 2), a fracture line is obtained that extends over a certain
35 thickness which corresponds to the post-fracture roughness that would be obtained if splitting annealing were continued over its entire duration.

As a result, the post-fracture roughness is intimately linked to the microcrack nucleation phase. A reduction in post-fracture roughness may then be achieved by controlling the phase for dissociation of the unstable
5 hydrogen-containing species supplying molecular hydrogen to the platelets during splitting annealing, such that it encourages the development of microcracks at the implantation peak to the detriment of the growth of platelets located above and below the restricted
10 microcrack zone. In this manner, microcrack/platelet interactions that contribute to an increase in post-fracture roughness are reduced.

In accordance with the present invention, the transfer method comprises at least one step of priming
15 annealing, the duration of which is less than 10% of the critical fracture time, i.e. the splitting annealing duration that is necessary to cause fracture of the implanted substrate as a function of the temperature employed. Following the priming anneal, the method of
20 the invention also includes a second step of implanting ions of at least one species (hydrogen, helium or any other active species) that can perturb the growth of microcracks and/or platelets during splitting annealing carried out in a continuous operation.

25 Some examples of carrying out the layer transfer method of the invention are described below. All of the examples described below pertain to the well-known fabrication of an SOI structure, which fabrication normally comprises at least the following steps:

- 30
- implanting a silicon donor substrate;
 - bonding the implanted donor substrate onto a silicon receiving substrate, for example by molecular bonding;
 - splitting annealing to allow fracture of the donor
35 substrate and transfer of a layer or a film of silicon onto the receiving substrate.

The examples described below were all carried out with a donor substrate of monocrystalline silicon with a thickness in the range from approximately 700 μm [micrometer] to 800 μm and a receiving substrate of monocrystalline silicon with a thickness in the range from approximately 700 μm to 800 μm .

Example 1

This example, which is described in relation to Figures 3A to 3E and 4, comprises the following steps:

- step S10: first hydrogen implantation in which a donor substrate 11 undergoes ionic bombardment 18 with hydrogen ions H^+ through the planar face 17 of a substrate comprising a layer of oxide (SiO_2) 12. H^+ ions are implanted is carried out with an implantation energy in the range 10 keV [kilo-electron volt] to 210 keV, for example 40 keV, and an implantation dose in the range 4×10^{16} atoms/ cm^2 to 1×10^{17} atoms/ cm^2 . These implantation conditions can create a layer of platelet type defects 13 parallel to the face 17 of the substrate, defining a thin film 14 in the upper region of the substrate 11 and a portion 15 in the lower region of the substrate corresponding to the remainder of the substrate 11 (Figure 3A);
- step S11: priming annealing at a temperature in the range 300°C to 700°C corresponding to the temperature normally used for splitting annealing. In accordance with the present invention, the duration of the priming anneal is less than 10% of the total time required to cause splitting of the implanted substrate at the temperature under consideration. This limitation in the duration of the priming anneal means that growth of the structural defects (microcracks and platelets) can be interrupted before the end of the transitional process and blistering of the silicon can be prevented (Figure 3B);

• step S12: second hydrogen implantation carried out by ionic bombardment 19 with hydrogen ions H^+ with the same energy as in the first implantation step to implant hydrogen to the same depth (Figure 3C). The first
5 implantation is carried out using a "normal" implantation dose to allow detachment of the layer to be transferred to be able to bring about and control the transitional process and nucleation of the microcracks. The implantation dose used during the second implantation
10 takes into account the dose used in the first implantation. By way of example, if the first implantation is carried out at an implantation dose of 5×10^{16} atoms/cm², the second implantation is carried out at an implantation dose in the range 1×10^{16} atoms/cm² to
15 3×10^{16} atoms/cm² to obtain a cumulative hydrogen implantation dose in the range 6×10^{16} atoms/cm² to 8×10^{16} atoms/cm². The second implantation is generally carried out at an implantation dose in the range 1×10^{16} atoms/cm² to 3×10^{16} atoms/cm²;
20 • step S13: bonding of donor substrate 11 with a receiving substrate 16 (Figure 3D);
• step S14: splitting annealing to cause fracture of the donor substrate 11 and transfer proper of the thin film 14 onto the receiving substrate 16 (Figure 3E).
25 After step S14, the thin film 14 has a post-fracture surface roughness in the range 60 angstroms (Å) to 70 Å root mean square (rms) and with a peak-to-valley amplitude for a scan area (for example using an atomic force microscope) of 10×10 microns in the range 800 Å
30 to 900 Å. By way of comparison, a similar thin film transferred from a donor substrate onto a receiving substrate using the widely used Smart Cut™ technique, i.e. with no priming annealing and the second implantation described above, has a post-fracture surface
35 roughness in the range 80 angstroms (Å) to 90 Å rms with a in peak-to-valley amplitude for scan areas of 10×10 microns in the range 1000 Å to 1200 Å.

Regarding step S11, in more detail, for an implantation dose of 5.75×10^{16} atoms/cm², the following is applied, for example:

- a priming anneal of slightly less than 1 minute at a temperature of 450°C when splitting annealing is carried out for a duration of 10 minutes at 450°C; or
- a priming anneal of slightly less than 5 minutes at a temperature of 400°C when splitting annealing is carried out for a duration of 50 minutes at 400°C; or
- a priming anneal of slightly less than 6 hours at a temperature of 350°C when splitting annealing is carried out for a duration of 60 hours at 350°C.

As explained above, limiting the priming anneal to 10% of the splitting annealing duration means that only a fraction of the first defect growth phase occurs, namely that corresponding to the onset of the transitional process in which the localized microcracks are partially formed and that in which the growth/development of platelets located above and below the microcracks is much more limited. The second hydrogen implantation at the localized microcrack growth zone will encourage their growth by increasing the quantity of hydrogen available to place them under pressure. During the subsequently applied splitting anneal, the end of the transitional process described above will be modified thereby. The end of nucleation of the microcracks partially formed during priming annealing then occurs differently. The localized microcracks then develop very rapidly and more laterally while limiting their direct interactions with the platelets located above or below their growth zone (less vertical deviation from the fracture line). A final fracture line is obtained that is much better localized in the initial microcrack zone, which means that the post-fracture roughness can be reduced.

Example 2

This example, which is described in relation to Figures 5A to 5E and 6, comprises the following steps:

- step S20: implantation of hydrogen, in which a
5 donor substrate 21 undergoes ionic bombardment 28 with hydrogen ions H^+ through the planar face 27 of a substrate comprising a layer of oxide (SiO_2) 22 under the same implantation conditions as those described for step S10, in order to create a layer of platelet type defects 23
10 parallel to the face 27 of the substrate, defining a thin film 24 in the upper region of the substrate 21 and a portion 25 in the lower region of the substrate corresponding to the remainder of the substrate 21 (Figure 5A);
- 15 • step S21: priming annealing at a temperature in the range 300°C to 700°C corresponding to the temperature normally used for splitting annealing. In accordance with the present invention, the duration of the priming anneal is less than 10% of the total time required to
20 cause detachment at the temperature employed. This limitation in the duration of the priming anneal means that growth of the structural defects (microcracks and platelets) can be interrupted before the end of the transitional process and blistering of the silicon can be
25 prevented (Figure 5B);
- step S22: sequential implantation of helium carried out by ionic bombardment 29 with He ions with an implantation energy determined as a function of the
30 implantation energy used during step S20, so that the maximum concentration of implanted helium coincides with the maximum concentration of hydrogen implanted in step S20 (Figure 5C). The skilled person is readily able to determine the implantation energy necessary during helium
35 implantation to obtain such a correspondence in the concentration maxima. Helium implantation is generally carried out using an implantation dose in the range 1×10^{16} atoms/cm² to 2×10^{16} atoms/cm²;

- step S23: bonding of donor substrate 21 with a receiving substrate 26 (Figure 5D);

- step S24: splitting annealing to cause fracture of the donor substrate 21 and transfer proper of the thin
5 film 24 onto the receiving substrate 26 (Figure 5E).

After step S24, the thin film 24 has a post-fracture surface roughness in the range 60 angstroms (Å) rms to 70 Å rms with a peak-to-valley amplitude for a scan area of 10 × 10 microns in the range 800 Å to 900 Å.

10 Regarding step S21, the examples given above for step S11 regarding the priming anneal duration are also applicable here.

As explained above, limiting the priming anneal to 10% of the splitting annealing duration means that only a
15 fraction of the first defect growth phase occurs, namely that corresponding to the onset of the transitional process in which the localized microcracks are partially formed and in which the growth/development of the platelets located above and below the layer is much more
20 limited. The second helium implantation at the localized microcrack growth zone will encourage their growth by supplying a large quantity of helium that will encourage pressurization thereof. During splitting annealing that is subsequently applied, the end of the transitional
25 process described above will be modified thereby. The end of nucleation of the microcracks partially formed during the priming anneal then occurs in a different manner. The localized microcracks then develop very rapidly and more laterally while limiting their direct
30 interactions with the platelets located above or below their growth zone (less vertical deviation from the fracture line). A final fracture line is obtained that is much better localized in the initial microcrack zone, which means that the post-fracture roughness can be
35 reduced.

Example 3

This example, which is described in relation to Figures 7A to 7E and 8, comprises the following steps:

- step S30: implantation of hydrogen in which a
5 donor substrate 31 undergoes ionic bombardment 38 with hydrogen ions H^+ through the planar face 37 of a substrate comprising a layer of oxide (SiO_2) 32 under the same implantation conditions as those described for step S10 in order to create a layer of platelet type defects 33
10 parallel to the face 37 of the substrate, defining a thin film 34 in the upper region of the substrate 31 and a portion 35 in the lower region of the substrate corresponding to the remainder of the substrate 31 (Figure 7A);
- 15 • step S31: priming anneal at a temperature in the range $300^{\circ}C$ to $700^{\circ}C$ corresponding to the temperature normally used for splitting annealing. In accordance with the present invention, the duration of the priming anneal is less than 10% of the total time required to
20 cause detachment at the temperature employed. This limitation in the duration of the priming anneal means that growth of the structural defects (microcracks and platelets) can be interrupted before the end of the transitional process and blistering of the silicon can be
25 prevented (Figure 7B);
- step S32: sequential implantation of fluorine carried out by ionic bombardment 39 with F ions with an implantation energy determined as a function of the implantation energy used during step S30 so that the
30 maximum concentration of implanted fluorine coincides with the maximum concentration of hydrogen implanted in step S30 (Figure 7C). The skilled person is readily able to determine the implantation energy necessary during fluorine implantation to obtain such a correspondence in
35 the concentration maxima. Fluorine implantation is generally carried out with an implantation dose in the range 8×10^{14} atoms/cm² to 1×10^{15} atoms/cm²;

- step S33: bonding of donor substrate 31 with a receiving substrate 36 (Figure 7D);

- step S34: splitting annealing to cause fracture of the donor substrate 31 and transfer proper of the thin
5 film 34 onto the receiving substrate 36 (Figure 7E).

After step S34, the thin film 34 has a post-fracture surface roughness in the range 60 Å rms to 70 Å rms with a peak-to-valley amplitude for a scan area of 10 × 10 microns in the range 800 Å to 900 Å.

10 Regarding step S31, the examples given for step S11 regarding the priming anneal duration are also applicable here.

In step S32, implantation may be carried out with other species such as silicon, nitrogen and carbon. In
15 general, step S32 consists of implanting into the substrate one or more species that can halt the growth of platelets that are located at least above the peak concentration of the implanted hydrogen. The species implanted during step S32 must be capable of reacting
20 with the implanted hydrogen, for example by creating bonds and/or interactions that allow them to form stable complexes with the implanted hydrogen. In these circumstances, the dissociation of hydrogen-containing species causing, by the formation of H₂, the platelets to
25 be placed under pressure is then retarded so long as the implanted hydrogen is not released from the stable complexes.

The implantation of species that can react with implanted hydrogen is carried out with an implantation
30 energy selected so that the maximum implantation concentration peak is located above or below the maximum hydrogen concentration peak so as not to halt the growth of microcracks during splitting annealing.

The implementations for the transfer method of the
35 invention described above can produce post-fracture roughness at the surface of the transferred thin film and at the surface of the portion of the non-detached donor

substrate portion in the range 60 Å rms to 70 Å rms. This level of post-fracture roughness is much lower than that obtained during a transfer carried out without the priming anneal of the invention. The level of post-

5 fracture roughness of a silicon substrate after splitting annealing is in the range 80 Å to 90 Å rms for the implantation of hydrogen alone and in the range 70 Å to 80 Å rms for hydrogen/helium co-implantation.

In general, it is also possible to replace steps

10 S14, S24 and S34 that consist of splitting annealing either by mechanical detachment (application of a blade, a jet or a fluid), or by partial splitting annealing (i.e. limited in duration) that is completed by mechanical detachment.

CLAIMS

1. A method of transferring a layer (14) of a donor substrate onto a receiving substrate (16), the method comprising:
- 5 a) a first step of hydrogen ions into the donor substrate (11), with the aim of forming a layer of microcavities or platelets;
- b) a second step of implanting ions;
- c) a step of bonding the face (17) of the donor
- 10 substrate (11) with a face of the receiving substrate (16);
- d) a step of detachment to cause splitting at the layer of microcavities or platelets formed in the donor substrate (11);
- 15 the method being characterized in that it further comprises, after step a) and before step b), a priming anneal heat treatment step carried out at a temperature in the range 300°C to 700°C and for a duration that is less than 10% of the duration necessary to cause
- 20 splitting at the layer of microcavities or platelets at the temperature employed during said priming anneal heat treatment.
2. A method according to claim 1, characterized in that
- 25 step b) consists in hydrogen ions into the donor substrate (11), implantation being carried out with the same implantation energy as that used in step a).
3. A method according to claim 1, characterized in that
- 30 step b) consists in helium ions into the donor substrate (21), implantation being carried out with an implantation energy that is determined as a function of that used in step a) so that the zone comprising the maximum concentration of implanted helium coincides with the zone
- 35 comprising the maximum concentration of hydrogen implanted during step a).

4. A method according to claim 1, characterized in that step b) consists in implanting ions into the donor substrate (31) of at least one species that can react with the hydrogen implanted during step a), implantation
5 being carried out with an implantation energy that is different from that used in step a).
5. A method according to claim 4, characterized in that said implantation of at least one species that can react
10 with the implanted hydrogen is carried out with an implantation energy determined as a function of that used in step a) such that the zone comprising the maximum concentration of said at least one species is located above the zone comprising the maximum concentration of
15 hydrogen implanted during step a).
6. A method according to claim 4 or claim 5, characterized in that the species that can react with the hydrogen implanted during step a) is at least selected
20 from fluorine, silicon, nitrogen and carbon.
7. A method according to any one of claims 1 to 6, characterized in that the hydrogen ions during step a) is carried out using an implantation dose in the range
25 4×10^{16} atoms/cm² to 1×10^{17} atoms/cm² and an implantation energy in the range from approximately 10 keV to 210 keV.
8. A method according to any one of claims 1 to 7,
30 characterized in that the donor substrate (11; 21; 31) is formed from a material at least selected from silicon, silicon-germanium and germanium.
9. A method according to any one of claims 1 to 8,
35 characterized in that the priming anneal heat treatment step is carried out at a temperature of 450°C for a duration of less than 1 minute, or at a temperature of

400°C for a duration of less than 5 minutes, or at a temperature of 350°C for a duration of less than 6 hours.

10. A method according to any one of claims 1 to 9,
5 characterized in that the layer (14; 24; 34) has, after step d), a post-fracture surface roughness in the range 60 Å to 70 Å rms with a peak-to-valley amplitude for scan areas of 10 × 10 microns in the range 800 Å to 900 Å.
- 10 11. A method according to any one of claims 1 to 10, characterized in that step d) comprises an anneal carried out at a temperature and for a duration that is determined to cause splitting at the layer of microcavities or platelets formed in the donor substrate
15 (11).
12. A method according to any one of claims 1 to 10, characterized in that step d) includes applying a mechanical force to cause splitting at the layer of
20 microcavities or platelets formed in the donor substrate (11).
13. A method according to claim 12, characterized in that step d) further includes a heat treatment.

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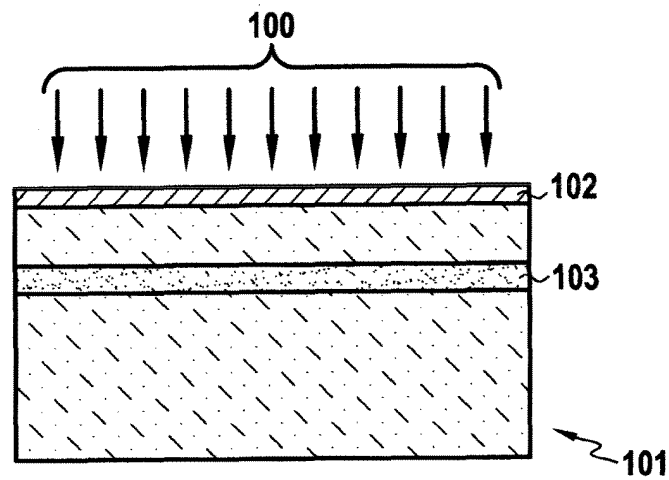


FIG.1

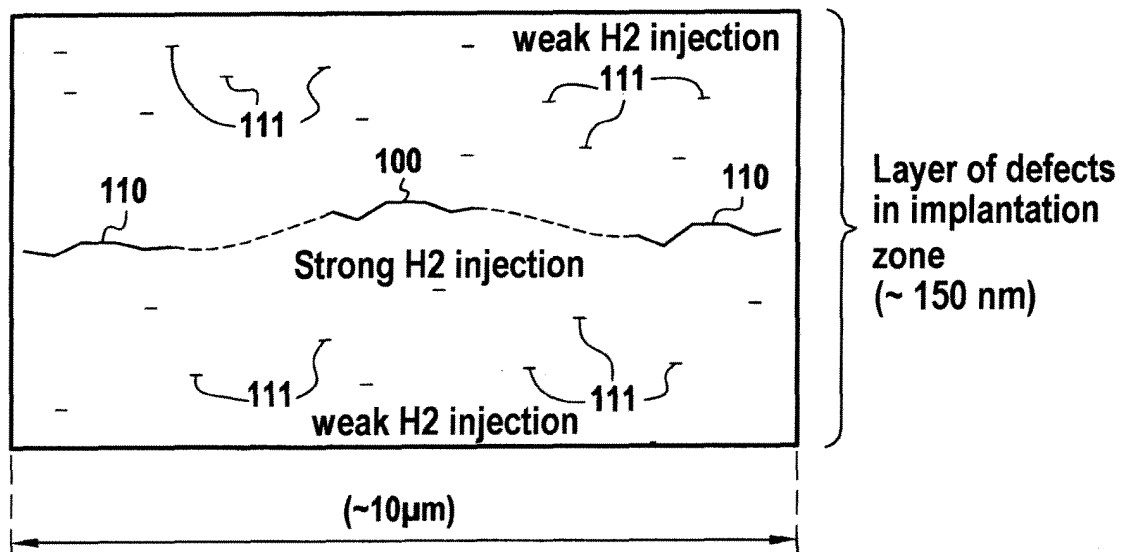


FIG.2

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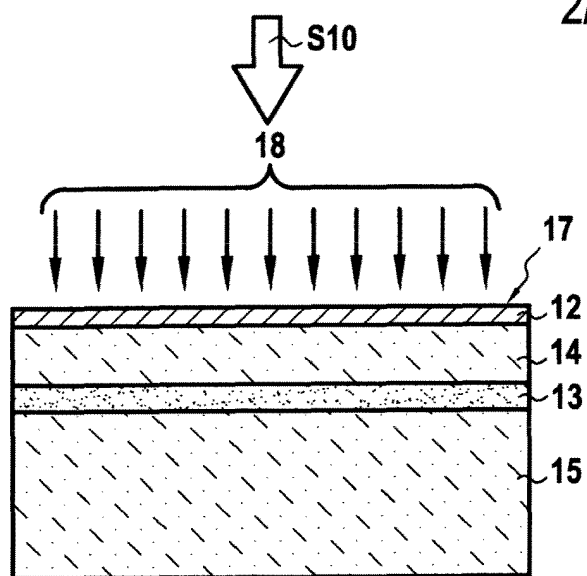


FIG. 3A

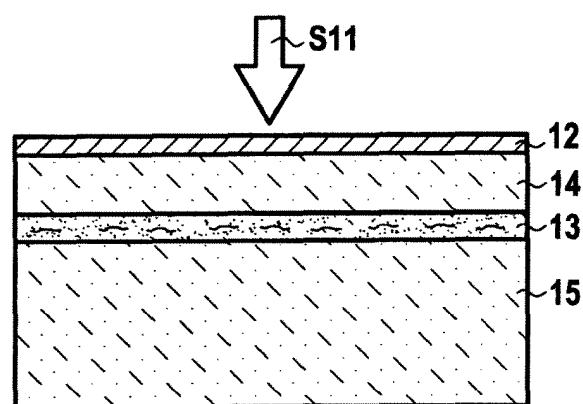


FIG. 3B

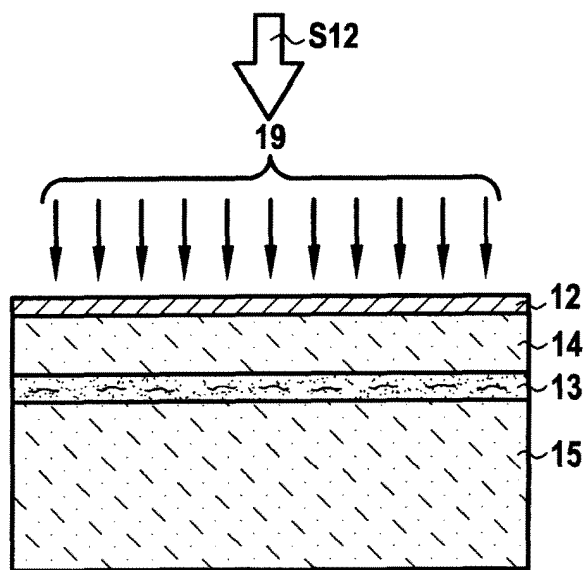


FIG. 3C

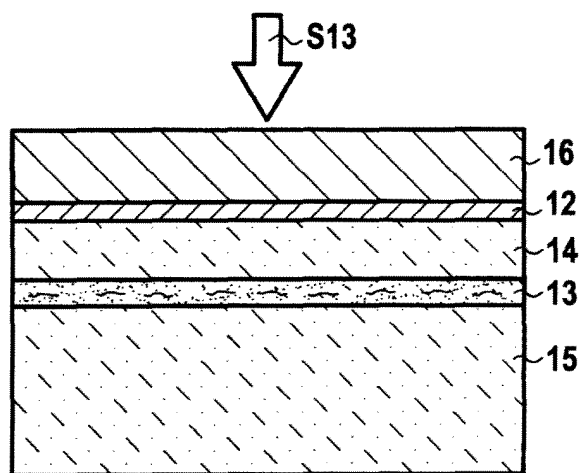


FIG. 3D

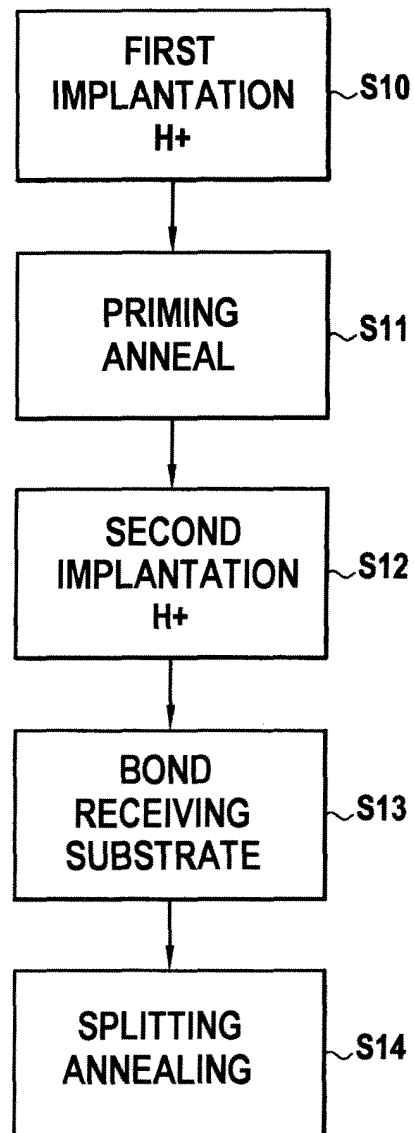
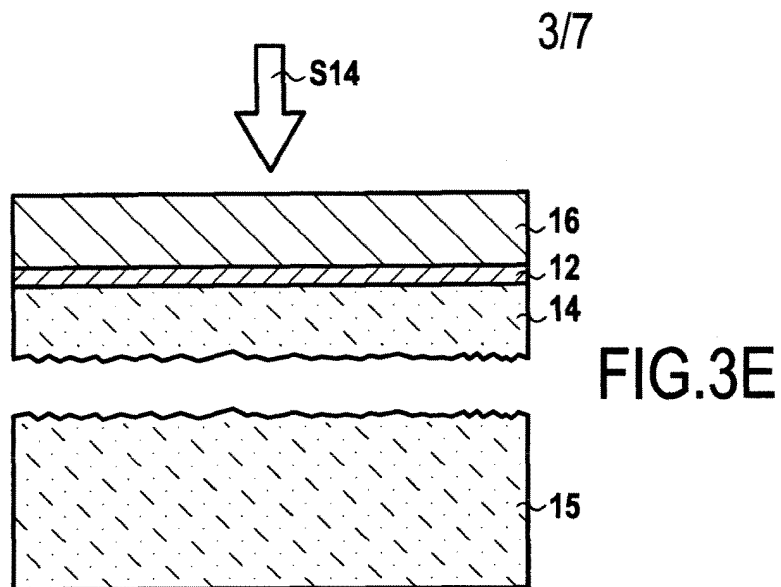
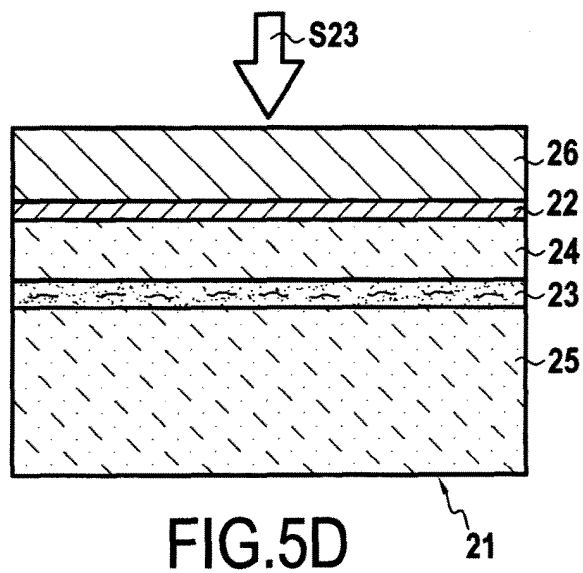
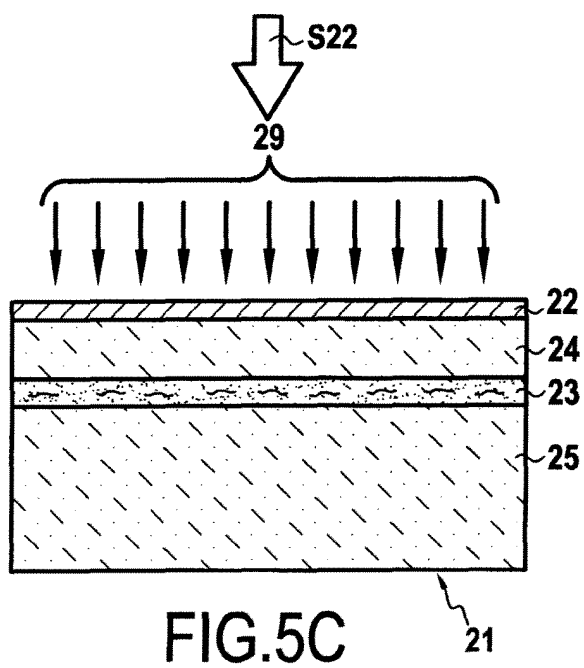
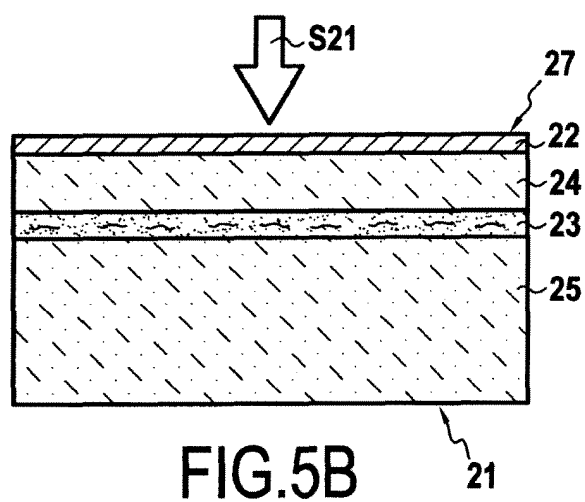
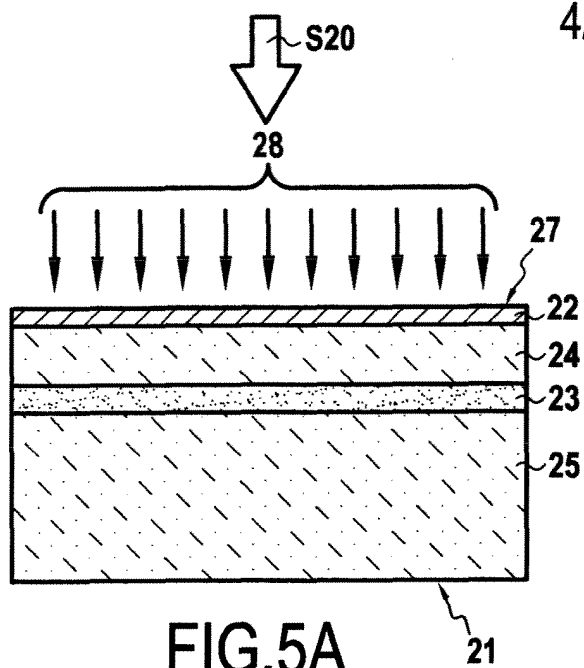
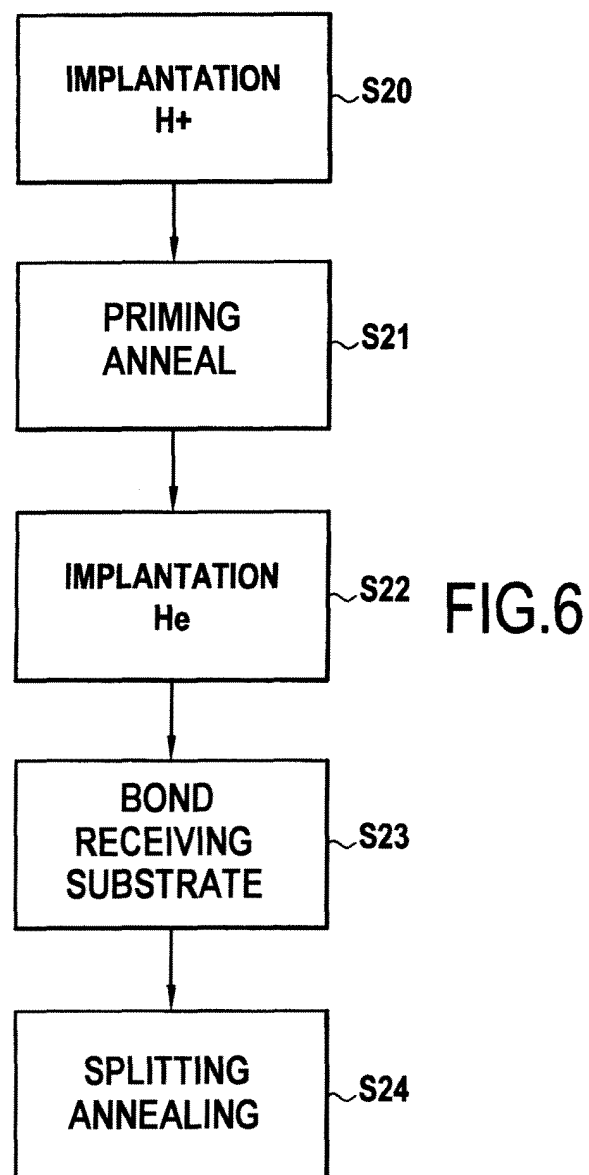
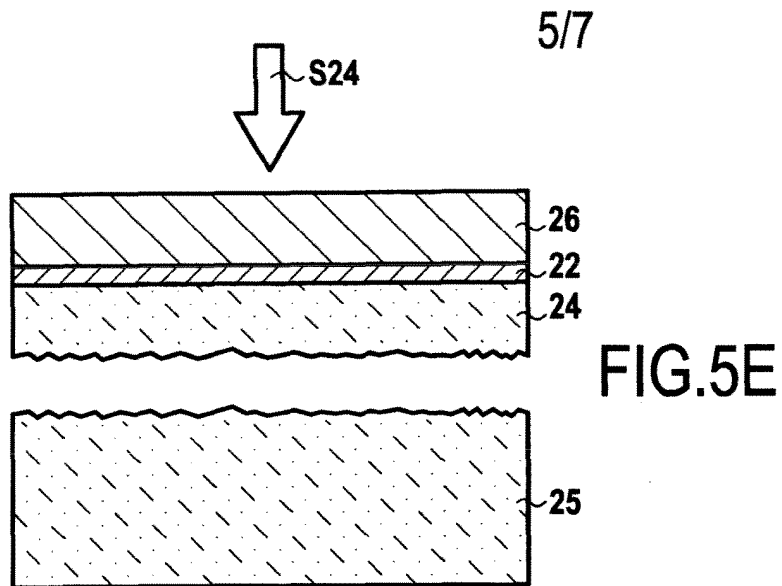


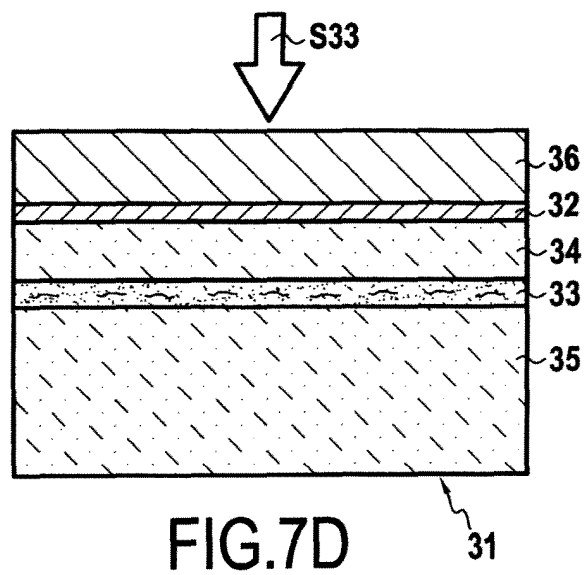
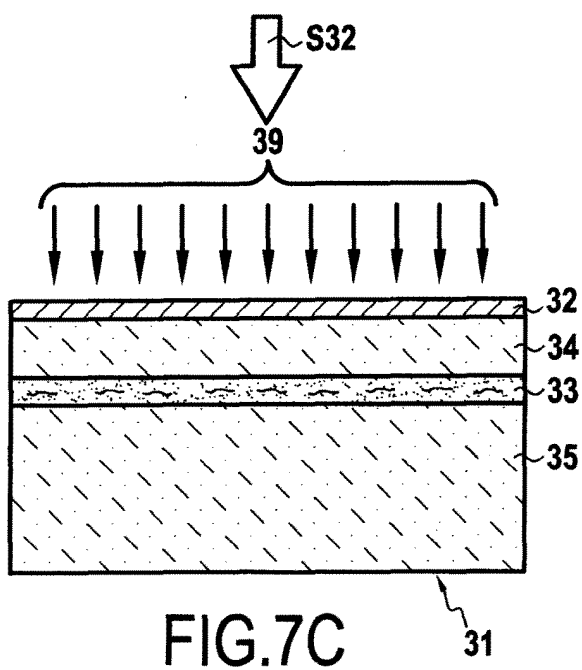
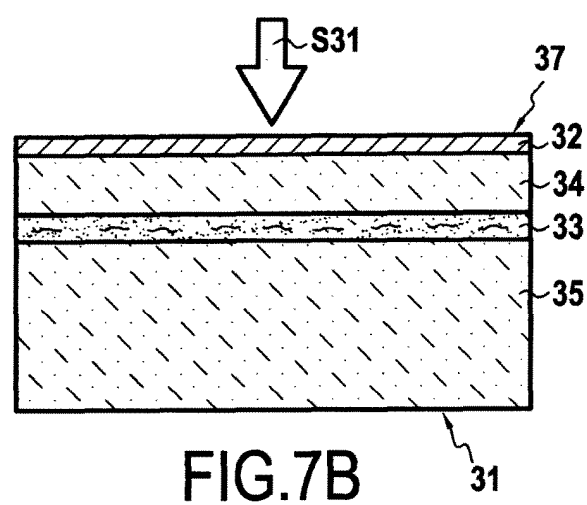
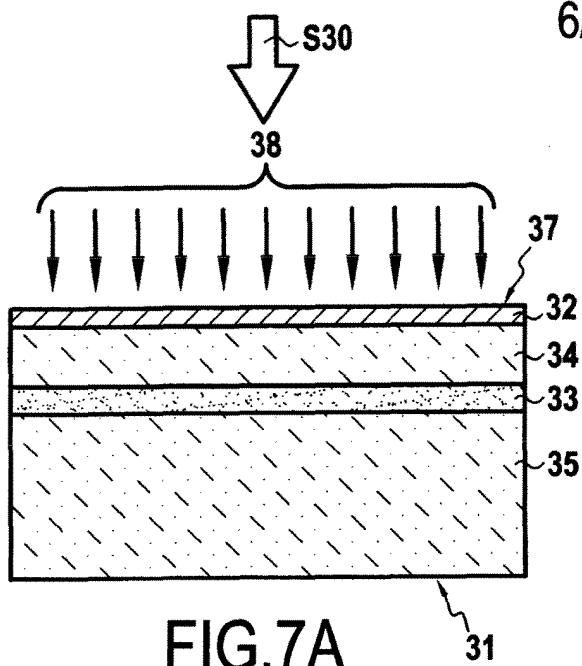
FIG.4

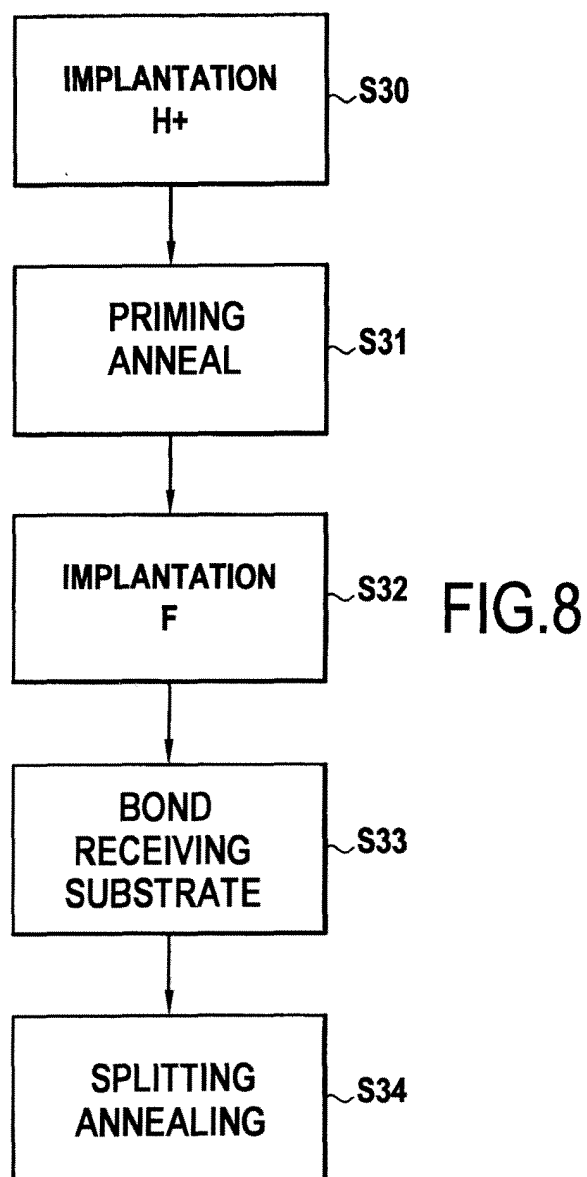
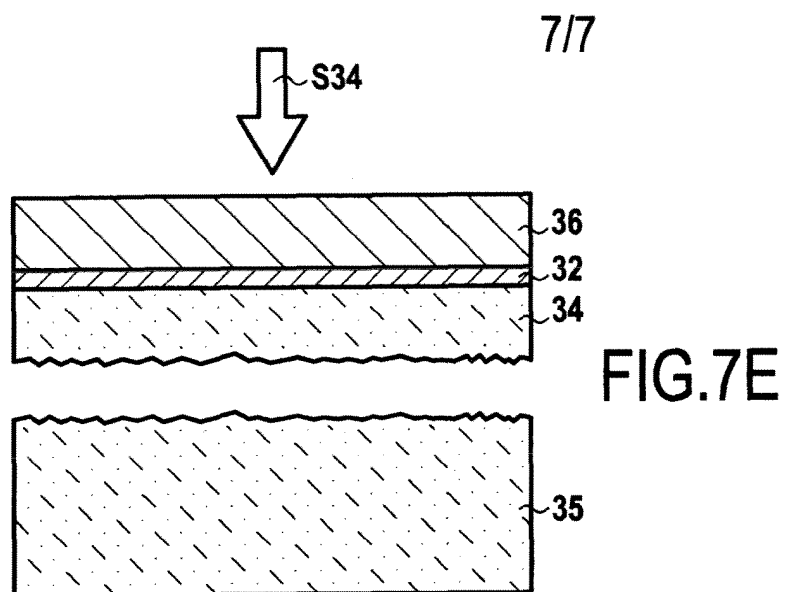
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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2008/067318

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L21/762

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
1 Y	US 2004/171232 A1 (CAYREFOURCQ IAN [FR] ET AL) 2 September 2004 (2004-09-02) page 2, paragraph 27 - page 4, paragraph 64	1-13
1 Y	US 6 150 239 A (GOESELE ULRICH M [US] ET AL) 21 November 2000 (2000-11-21) column 3, line 60 - column 9, line 62	1-13
1 A	EP 1 429 381 A (SOITEC SILICON ON INSULATOR [FR]; COMMISSARIAT ENERGIE ATOMIQUE [FR]) 16 June 2004 (2004-06-16) page 5, line 13 - line 25	9
1 Y	US 7 148 124 B1 (USENKO ALEXANDER YURI [US]) 12 December 2006 (2006-12-12) column 1, line 17 - column 14, line 57; figures 4,6	1-13



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

25 March 2009

Date of mailing of the international search report

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040.
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Lyons, Christopher

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2008/067318

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