Method for the catastrophic transfer of a thin layer after co-implantation

Field of the invention

The invention relates to a method of transferring an ultrafine film (the term thin or ultrathin film is also used) at low temperature by the method of co-implantation. It has applications in particular in the fields of micro-electronics, micro-mechanics, optics and integrated electronics.

State of the art

As is known, splitting a thin film may be achieved by implantation of chemical species in a source substrate, for example of silica, to induce the formation of a zone of defects at a particular depth. These defects may be micro-bubbles and/or platelets and/or micro-cavities and/or dislocation loops and/or other crystalline defects, locally disrupting the crystalline quality of the material; their nature, density and size are strongly dependent on the species implanted (typically hydrogen) as well as on the nature of the source substrate. A heat-treatment may then be applied to enable the development of specific defects present in the weakened zone, which enables splitting of the thin film from the source substrate to be achieved later, in

principle by subjecting the defects to pressure. This has in particular been described in the document US-5 374 564 and developments thereof, such as the document US-6 020 252.

Splitting may be made, generally further to heat treatment, by applying an external force which induces fracture in the weakened zone until splitting is achieved of the thin film.

When the splitting is produced at high temperature (typically near approximately 500°C), among the technological problems encountered, mention should be made of the roughness of the surface as well as the degradation of the film transferred during the thermal splitting. This renders the following treatment steps more difficult (for example: the transferred film must be polished more, there is a risk of crystalline defects being created during the following treatments, etc.). Furthermore, in heterostructures (comprising a superposition of substrates of different materials), another technological problem encountered is the presence of a field of very high stresses in the various films in contact, during the heat treatment, due to the difference in the coefficients of thermal expansivity of the various materials placed in contact. This may induce the degradation of the heterostructures if the thermal splitting occurs at a temperature higher than a critical temperature. This degradation may, typically, be the breakage of one or both substrates brought into contact and/or be the unbonding of the substrates at the bonding interface.

This is the reason why it may be desired to achieve the splitting at lower temperature.

One way to achieve splitting at low temperature is to "play" with the implantation conditions. For example, an excess dose of the implanted species may

increase the weakening of the implanted zone in which the splitting at low temperature occurs.

Thus Henttinen et al. (2000) [1] showed that, if the source substrate is a wafer of silicon, a dose of hydrogen ions implanted at 1 x 10^{17} H^+/cm^2 (i.e. 5 x 10^{16} H_2/cm^2), enables splitting by a mechanical force after performing the following steps: treatment, as for the target substrate, by a plasma chemical activation; cleaning of RCA1 type, bonding at ambient temperature of the source substrate onto the target substrate, and annealing at 200°C for 2 hours. The mechanical force utilized came from a blade inserted at the bonded interface to initiate the splitting.

This approach, although reducing the roughness of the transferred surface (by of the order of half with respect to conventional splitting solutions that are purely thermal and without plasma activation), involves a step of plasma chemical activation followed by RCA1 cleaning, which may represent a significant drawback from an industrial point of view (high cost).

Moreover, it is important to note that, due to the high dose of hydrogen implanted, the heat treatment after bonding must not exceed 300°C, the temperature at which thermal splitting could occur, in which case the aforementioned advantage of the reduction in roughness of the transferred surface would not be achieved: a step of plasma chemical activation, followed by RCA1 cleaning is thus indispensable for reinforcing the bonding before its thermal consolidation according to the technique described by HENTTINNEN.

It is important to note that, in fact, it is not solely the temperature of treatment which affects the later conditions of splitting of the thin film, but also the duration of that treatment, which has resulted in the concept of thermal budget (see FR-2 767 416 - CEA); as

for the provision of mechanical energy, this is for example provided by a tool of "guillotine" type (see WO 02/083387 - SOITEC).

Thus, it has been found that, if the thermal budget is too low, the transfer of the thin film is of poor quality, whereas if it is too high, fracture may occur of one of the substrates in the case of a heterostructure. It can thus be understood that in principle there exists a narrow window for the operational parameters, (related, naturally, to the conditions, in particular the implanted doses, the nature of the materials, the temperatures of annealing, etc.), but this narrowness constitutes a heavy constraint for industrial exploitation.

Furthermore, the mechanical splitting often consists of introducing one or more blades from the edges of the structure, as if to "cut it out" along the weakened zone; the term 'assisted splitting' is sometimes used, since the role of the tool (such as a blade) is to propagate the fracture wave from one edge of the structure to the other.

This type of fracture leads to the following defects, at the future surface freed by the splitting of the thin film:

- crown defect (non-transferred zone, at the periphery of the final product), for example related to a local bonding energy too low with respect to the rest of the interface, and to the introduction of tools to start off the transfer,
- lack of uniformity (low frequency roughness) of the thickness of the thin film transferred, in particular due to the fracture wave assisted mechanically, thus irregular, by fits and starts, which then necessitates treatments,

such as polishing, which it is however generally sought to avoid,

- difficult industrial implementation, given the use of a tool which accompanies the propagation of the fracture, which implies an individual treatment of each structure (or wafer).

Most of these drawbacks are found in the case of the splitting of a thin film in a homogeneous substrate (with a single component material (SOI, for example).

The splitting of the thin layer is of course also determined by the choice of the chemical species implanted.

It was indicated above that hydrogen is generally implanted, but other options have been proposed, in particular by implanting helium.

Combination may even be made of two different chemical species.

Thus Agarwal et al. (1998) [2] found that the fact of implanting both hydrogen and helium enabled the total implanted dose of ions to be reduced, apparently due to the different roles played by hydrogen and helium: the hydrogen interacts with the Si-Si bonds broken by the implantation, to create Si-H bonds, resulting in a high density of platelet type defects of a size of the order of 3-10 nm (termed H-defects of platelet type), whereas helium, which does not act chemically, leads to the apparition of a lower density of larger defects (size greater than 300 nm approximately). The heat treatments envisaged in that article are 450°C for 20 min or 750°C for 20s, which necessarily implies the drawbacks mentioned above in relation to splitting at high temperature.

This hydrogen-helium combination has also been studied, in a more theoretical manner, by Cerofolini et al. (2000) [3], who noted that pressurization of the

defects was greater with the implantation of helium than with that of hydrogen, and that the heat treatment could have different effects according to the temperature chosen: annealing between 150°C-250°C leads to a reduction in the number of Si-H bonds, annealing in the range 300°C-450°C leads on the contrary to an increase in that number, whereas annealing above 550°C tends instead to reduce that number again. However that article does not deduce practical conclusions therefrom as to the manner of obtaining thin films of good quality (in particular in relation to the state of the surface) for a moderate cost.

The object of the invention is to alleviate the drawbacks described above.

More particularly, the invention relates to a method of transferring a thin layer leading to low roughness of the surface of the transferred layer, and not involving high mechanical stresses in case of materials having high differences in expansion coefficients. In other words, the object of the invention is to obtain, for a moderate cost, thin films of high quality, thereby avoiding at the same time the drawbacks of a heat treatment at high temperature and those related to the utilization of a tool for assisted splitting, and those related to an additional treatment for reducing roughness after splitting.

Presentation of the invention

To that end the invention provides a method of catastrophic transfer of a thin film according to which:

- a source substrate is prepared,
- a first species of ions or gas in a first dose is implanted in that source substrate at a given depth with respect to a face of that source substrate, and a second species of ions or gas in a second dose, that

first species being adapted to generate defects and the second species being adapted to occupy those defects,

- a stiffener is applied in intimate contact with the source substrate,
- a heat treatment is applied to that source substrate, at a given temperature for a given time, so as to create, substantially at the given depth, a buried weakened zone, without initiating the thermal splitting of the thin film,
- a localized amount of energy is applied to that source substrate so as to provoke the catastrophic splitting of a thin film delimited between the face and the buried weakened layer, with respect to the remainder of the source substrate, that thin film having, opposite to said face, a face of which the roughness is less than a given threshold.

Catastrophic splitting may be defined here as being a complete and virtually instantaneous splitting, similar to that obtained by a simple heat treatment at high temperature, but possibly induced by a tool without it having to follow any kind of fracture wave (if there is a tool, it comes at most into contact with the substrate and the film, without following the splitting interface); this is thus, in other words, the result of a catastrophic propagation of a fracture wave, which is to say the contrary of an assisted splitting.

By self-supported propagation of the fracture wave, it is understood that it is not necessary to assist the propagation of the wave by advancing a tool or repeating the initiation energy pulse. Also, an important feature of the invention is that the fracture wave is propagated over the whole of the surface of the wave in less than 1 second, even of the order of one millisecond (speeds greater than 100 m/s) for diameters up to 300 mm.

One possible origin of the self-supported (or

catastrophic) fracture stems from the nature of the buried defects. Research (on germanium, but applicable to silicon) has shown that under C-splitting conditions (that is to say … TO BE COMPLETED)the density of defects (microcracks, cavities, platelets, microbubbles, macrobubbles, etc.) is from 0.03 to 0.035 per square micron, their sizes are of the order of 7 to 8 square microns, and, in what appears to be a more characteristic manner, the area opened up by these defects as a percentage of the total area of the wafer is estimated to be from 25 to 32%. These values are similar to those obtained if the fracture is obtained by thermal means, but different from those obtained after weakening treatment that necessitates assisted mechanical fracture (in which case these values are more … TO BE COMPLETED). Of course, other effects or causes are not excluded by this interpretation; in particular the chemical nature of the bonds in the substrate may also promote the occurrence of the self-supported fracture wave phenomenon.

In other words, one aspect of the invention seems to consist in promoting the weakening conditions close, in their nature, to the conditions obtained in the case of thermal fracture, without going so far.
The additional energy is then provided by localized addition of energy.

More precisely, the invention is based on the implantation of two different species. One of the implanted species localizes, depending on its implantation energy, the zone in which splitting will later occur by the formation of specific defects, the other corresponds to a type of atoms trapped in that zone which will promote the extension of the specific defects designated previously, apparently: by increasing the weakening of the implanted zone at relatively low

temperature by preventing, in the case of the implantation of a silicon substrate by hydrogen, the Si-H dissociation (thereby promoting the H-defects of platelet type) and putting those defects under pressure.

The heat treatment temperature is advantageously chosen so as to promote the defects of platelet type without however inducing thermal splitting. This temperature will be sufficiently low not to generate high mechanical stresses in the substrate should the source substrate and/or a possible target substrate comprise materials having very different coefficients of expansion. It is for this reason that the method is a method of transfer occurring at a relatively low temperature (no higher than 400°C to avoid the escape of the helium, in the case of hydrogen-helium co-implantation).

It is worth stressing that, according to the invention, by co-implanting two gaseous species, such as hydrogen and helium, and by thermally weakening the structure at low temperature (below the aforementioned threshold of 400°C, or even below 300°C), it has been observed that, in a completely surprising manner, the nature of the splitting is changed; weakening the implanted zone is achieved to a very high degree without generating purely thermal splitting, regardless of the annealing time (no splitting observed after 24h of annealing at the low temperature defined above), by contrast, splitting occurs catastrophically, by simple provision of energy localized in time and in space (such as a mechanical shock at the weakened interface, for example). It would thus appear that the concept of thermal budget set out in the aforementioned document FR - 2 767 416 is not appropriate in the case of co-implantation with a heat treatment at low temperature in the conditions stated earlier.

The consequences of this are significant:

- the operational window of the pre-weakening annealing step is enlarged: there no longer exists (or it is considerably offset) a maximum bound for the duration of that pre-weakening annealing; this is entirely favorable to the industrialization of the method,
- There is no longer assisted splitting since the catastrophic fracture enables the fracture wave to be propagated instantaneously and without fits and starts over the entire section of the wafer; it is not necessary for any blade whatsoever to penetrate between the substrate and the future thin film, which considerably improves the topology of the surfaces thus freed (thus with lower roughness), and avoids crown defects, which makes the entire thin film usable, including its periphery; the fact of no longer having to introduce a tool is also favorable to the industrialization of the method.

The inventors do not yet have clear explanations for this new kinetics.

Given that, at latest at the moment of the heat treatment, the source substrate is placed in intimate contact by said face with a stiffener or target substrate, the heat treatment contributes to improving the bonding energy between those substrates.

The localized provision of energy is preferably applied in the form of a shock or pulse. It may advantageously be applied by a tool imparted with movement that is brief and of small amplitude.

It is advantageously applied in the immediate proximity of the buried layer, limited only to a part of the latter, preferably to a peripheral portion of the

latter.

This provision may in particular be constituted by a localized thermal provision (for example applied by a laser pulse) or by an external force (for example in the immediate proximity of the weakened layer, at an edge of the latter).

In fact, tests with a co-implantation of hydrogen and helium in the source substrate in the conditions of the invention have lead to catastrophic splitting, that is to say to complete and virtually instantaneous splitting, with a continuous and planar propagation of the fracture wave, initiated with the help of a very low localized provision of energy, which in particular had the advantage of avoiding surface undulations, that is to say avoiding large variations in surface roughness after fracture, in comparison with progressive splitting. Due to this, that catastrophic splitting implies less polishing afterwards.

It is worth stressing that it could apparently seem difficult to define a method guaranteeing low roughness further to splitting at low temperature without plasma activation, since a low temperature would not seem to allow sufficiently solid bonding between source substrate and target substrate due to a weak bonding interface. Naturally, the method according to the invention may without detriment utilize a plasma activation of at least one of the surfaces to be placed in contact, but in contrast to the technique described by HENTTINEN, that activation is not indispensable.

Preferentially, the implantation of the species creating defects which promote splitting is made after the implantation of the second species which is made so as to localize that second species in the zone of the defects created by the first species.

Advantageously, in the case of silicon, that

first species is hydrogen (preferably in the form of H^+ ions), which is implanted in standard concentration (typically of the order of a few 10^{16} H/cm^2), it being recalled that hydrogen exhibits a high efficiency in creating a weakened zone. At that layer, the second species (preferably helium), playing the role of atoms trapped to promote the formation of the weakening defects, is implanted at a relatively low dose (typically of the order of 10^{16} He/cm^2, or a few 10^{16} He/cm^2).

When the source substrate has been bonded to a target substrate, the effect of the heat treatment at low temperature (which is nevertheless sufficient to obtain good solidity of the bonding interfaces) is that the atoms of the second helium species diffuse into the defects created by the hydrogen. The maximum weakening obtained at that relatively low temperature enables splitting to be made of an ultra-fine film which is of very low roughness (of the order of a few nm), initiated by an external force.

The radical difference in this method, with respect to the technique described by Henttinen, is that it is not necessary to carry out excess dosage of the hydrogen which can greatly damage the implanted zone. The effect of the co-implantation makes it possible to achieve the maximum weakening of that zone at the temperature sufficient for solidity of the bonding interfaces without involving additional processes (plasma chemical activation and RCA1). Furthermore, the invention leads to better roughness of the transferred film in comparison with that obtained by thermal splitting.

Advantageously, the second species (for example helium) is implanted at the same level as the first (hydrogen) but as a variant it may be implanted at a greater offset depth (for example) in the source substrate to reduce the zone degraded by the

implantation. This offset level may be clearly distinct from the first, for example much deeper in the source substrate. In this case, it appears that a small part of the second implanted species is trapped by the defects encountered on its implantation path.

In fact, the co-implantation enables a temperature of 200°C to 400°C to be chosen.

Preferably, the source substrate is of a material chosen from semi-conductors and insulators, monocrystalline, polycrystalline or amorphous. Thus it may be chosen from the semi-conductors IV (a particularly attractive example is silicon but it may also be germanium or Si-Ge alloys, in particular).

At least in this case, the temperature of heat treatment is advantageously chosen in the range 200°C-400°C, preferably in the range 300°C-350°C, for example for a duration of a few hours (typically of the order of 2 to 5 hours). The source substrate may also be a semi-conductor material of III-V type (for example As Ga or InP) or of an insulating material preferably chosen from the group comprising LiNbO3 and Li TaO3.

The heat treatment may also have a profile adapted to reduce the time of that treatment, as is for example disclosed in European patent application No. 02-293049 filed on December 10, 2002.

In fact, the temperature range depends principally on the nature of the species implanted and on the nature of the material constituting the source substrate.

The target substrate or stiffener is advantageously chosen in the form of an amorphous material, preferably in the form of fused silica. However, it may also be a monocrystalline or polycrystalline material, of silicon or sapphire, in particular.

General description

Aims, features and advantages of the invention will appear from the following description, given by way of non-limiting illustration with reference to the accompanying drawing in which:

- Figure 1 is a diagram of a source substrate during implantation,
- Figure 2 is a later view of it after putting in intimate contact (bonding) with a target substrate; and
- Figure 3 is a view of it during splitting of a thin film deriving from the source substrate.

Figure 1 thus shows a substrate 1, for example of silicon advantageously oxidized on its surface 4, while being subjected to an implantation treatment, represented by the arrows 2, for example by bombardment with ions or gaseous species.

This implantation involves, at a given depth, implantation of a first species which is adapted to generate defects, for example hydrogen, preferably in the form of H^+ ions, and implantation of a second species, for example helium, adapted to occupy those defects. In the case represented, both species are implanted at the same depth, but in a variant form, the second species is implanted at a depth different from the first, for example at a greater depth.

Commencement is advantageously made by implanting the first species, i.e. hydrogen, further to which the helium may occupy the defects so created, as from its implantation. However, the inverse order of the implantations is possible, even if the two implantations are not made at the same depth.

A buried zone 3 results from this, weakened by the presence of defects, principally generated by the

first species, to the development of which the second species will contribute.

The weakened zone 3 delimits, within the source substrate, a future thin film 5 and a substrate remainder 6, that is to say that which remains of the source substrate after splitting of the thin film; this remainder will be able to serve as source substrate for a new implementation cycle of the procedure.

Figure 2 represents a step during the course of which the source substrate, containing the buried weakened zone 3, is placed by its face 4, into intimate contact with a corresponding face of a target substrate 7, typically by direct molecular bonding, whose function is that of a stiffener.

A heat treatment is then applied which will, on the one hand, enable development of the weakening of the buried layer 3, and on the other hand, when a bonding step has taken place, enable consolidation of the bonds between source substrate and target substrate.

More particularly, the temperature of this heat treatment is chosen from the range of temperatures suitable for developing the weakened zone, that is to say the Si-H bonds in the present case.

This treatment is advantageously carried out at a temperature chosen from the range 200°C-400°C, preferably from the range 300°C-350°C, for a duration typically chosen of a few hours, for example 2 hours. Thus, the thermal budgets (temperature-duration pairs) are industrially realistic.

In Figure 3 there is represented the step of splitting of the thin film 3 from the remainder of the source substrate, by means of the application of a local provision of energy, preferably brief and of limited amplitude, for example in the form of a shock or pulse.

It is for example constituted by a mechanical

stress represented by the arrow 10.

The splitting obtained is catastrophic in the sense that, in particular, there is no movement of a tool along the weakened layer.

This local provision of energy is here limited to a part of the buried layer, represented in the form of a corner effect corresponding to a shock applied by a tool such as a blade on (or proximal to) a portion of that buried weakened layer; but it may be of any other nature, for example a couple parallel to the plane of the buried weakened layer advantageously applied in the form of a pulse of small angular amplitude. By virtue of the method of the invention, the face of the thin film which is freed by the catastrophic splitting in the buried weakened zone (in practice substantially planar) has a roughness Ra considerably less than with the conventional solutions, without it having been necessary to provide a particular treatment of the surfaces transferred nor substantial ("coarse") polishing after splitting. It is worth noting that, since splitting is catastrophic, there is no real propagation in fits and starts of a fracture wave liable to generate surface waves, and that, since there is no movement of any tool along newly created surfaces (or relative movement between the two parts on each side of the buried layer) there is no degradation of the surfaces thus freed, which therefore have a very smooth surface state, induced by the catastrophic splitting.

The source substrate 1 may not only be of silicon, but more generally of any appropriate known material for example a IV or III-V semiconductor, monocrystalline or polycrystalline or even amorphous. Thus the source substrate may be:

- another semiconductor of column IV of the periodic table of the elements, for example of

germanium,

- a semiconductor of type III-V such as AsGa or InP, in particular,
- an insulator, for example of niobate or tantalate type, such as $LiNbO_3$ or $LiTaO_3$, in particular.

The target substrate may be of a wide variety of materials, to be chosen according to needs, monocrystalline or polycrystalline (for example semiconductors, for example from among the same materials as for the source substrate) or even be amorphous (for example types of glass, or polymers); thus it may in particular be:

- a crystalline material such as sapphire,
- of fused silica or of another glass,
- a simple stiffening layer, for example of oxide a few tens of nanometers thick, deposited by any appropriate known technique (this admittedly no longer corresponds to a bulk target substrate of the type represented in the drawings).

It is worth noting that the target substrate may be just an intermediate substrate from which the thin film is later transferred onto a final substrate.

Examples

According to a first embodiment of the invention, a substrate of Si (~700µm) comprising a layer of thermal SiO_2 on the surface (for example 145nm) may be implanted initially with helium atoms under implantation conditions of 70keV-1 x 10^{16} He/cm², and then be implanted with hydrogen atoms under implantation conditions of 30keV-4.25 x 10^{16} H/cm². This source substrate may next be joined to a target substrate of Si (~700µm) by direct bonding. A heat treatment around 350°C induces the growth

of cavities of platelet type localized at the hydrogen concentration peak. The helium atoms play the role of atoms trapped thereat and create a maximum of defects of platelet type at the applied temperature. After a certain time (for example 2 hours), with scarcely the commencement of insertion of a blade between the bonding interfaces in the form of a shock, catastrophic splitting at the location of maximum hydrogen concentration leads to the transfer of the thin film of Si onto the target substrate. The roughness of the surface transferred measured at high frequency (by atomic force microscopy), of the order of 45 to 50 angstroms, and at low frequency (by profilometric method), of the order of 10 angstroms, and amorphousness of that transferred surface are substantially less than those which may be obtained in the case of H-implanted alone ($32keV-5.5x10^{16}H/cm^2$) followed by a heat treatment at 500°C (roughness at low frequency of the order of 26 angstroms and roughness at high frequency of the order of 75 angstroms).

According to another embodiment of the invention, a substrate of Si (approximately 300µm) comprising a layer of thermal SiO_2 on the surface (for example 200nm) is implanted initially with helium atoms under implantation conditions of $70keV-2x10^{16}He/cm^2$, and then implanted with hydrogen atoms under the conditions of $30keV-3x10^{16}H/cm^2$. This source substrate is then joined to a target substrate of fused silica (approximately 1000µm) by direct bonding. A heat treatment around 300°C induces the growth of cavities of platelet type localized at the hydrogen concentration peak, the implanted atoms of helium trapped by the hydrogen defects favoring the formation of a maximum of the defects of platelet type at the applied temperature. After a certain time (3 hours for example), by means of a blade only scarcely inserted between the bonding interfaces and imparted with a

movement pulse (i.e. a shock), catastrophic splitting at the maximum of the hydrogen profile leads to the transfer of the Si thin film onto the fused silica substrate, without breakage or degradation of either of the substrates derived from the heterostructure after splitting (the fused silica substrate having the thin film of Si on the one hand, and the initial Si substrate having had the superficial thin film peeled from it on the other hand). The roughness of the surface transferred, measured at low frequency by profilometric method (of the order of 14 angstroms at low frequency and of the order of 75 angstroms at high frequency) and amorphousness of that transferred surface are substantially less than those which may be obtained in the case of H-implanted alone (32keV-5.5×10^{16}H/cm^2) using the progressive mechanical splitting method at high temperature (roughness at high frequency of the order of 90 angstroms and at low frequency of the order of 40 angstroms).

References

[1] K. Henttinen et al., Applied Physics Letters, Volume 16, Number 17, 24 April 2000 ; pp. 2370-2372

[2] A. Argawal et al. Applied Physics Letters, volume 72, Number 9, 2 March 1998 ; pp. 1086-1088

[3] G. F. Cerofolini et al., Materials Science and Engineering B71 - 2000, pp. 196-202

CLAIMS

1. Method of catastrophic transfer of a thin film according to which :

- a source substrate is prepared,
- a first species of ions or gas in a first dose is implanted in that source substrate at a given depth with respect to a face of that source substrate, and a second species of ions or gas in a second dose, that first species being adapted to generate defects and the second species being adapted to occupy those defects,
- a stiffener is applied in intimate contact with the source substrate,
- a heat treatment is applied to that source substrate, at a given temperature for a given time, so as to create, substantially at the given depth, a buried weakened zone, without initiating the thermal splitting of the thin film,
- a localized amount of energy is applied to that source substrate so as to provoke the catastrophic splitting of a thin film delimited between the face and the buried weakened layer, with respect to the remainder of the source substrate, that thin film having, opposite to said face, a face of which the roughness is less than a given threshold.

2. Method according to claim 1, characterized in that the localized provision of energy is applied to a small part only of the buried weakened layer.

3. Method according to claim 2, characterized in that the localized provision of energy is applied in the form of a localized thermal provision.

4. Method according to claim 2, characterized in that the localized provision of energy is applied in the form of a movement that is brief and of small amplitude applied by means of a tool.

5. Method according to claim 2, characterized in that the localized provision of energy is applied in the form of a shock in a peripheral zone of the buried weakened layer.

6. Method according to any one of claims 1 to 5, characterized in that the stiffener with which the source substrate is placed in intimate contact, at latest at the moment of the heat treatment, is a target substrate, the heat treatment contributing to improving the bonding energy between those substrates.

7. Method according to claim 6, characterized in that the target substrate is of an amorphous material.

8. Method according to claim 6, characterized in that the source substrate is of silicon and the target substrate is of fused silica.

9. Method according to claim 6, characterized in that the target substrate is of a monocrystalline or polycrystalline material.

10. Method according to claim 9, characterized in that the target substrate is of silicon.

11. A method according to any one of claims 1 to 10, characterized in that implanting of the first species is carried out after that of the second species.

12. Method according to any one of claims 1 to 11, characterized in that the source substrate is prepared from a material chosen from semiconductors and insulators, monocrystalline, polycrystalline or amorphous.

13. Method according to claim 12, characterized in that the source substrate is prepared from a material chosen from the IV semiconductors.

14. Method according to claim 13, characterized in that the source substrate is made from silicon.

15. Method according to any one of claims 1 to 14, characterized in that the heat treatment is performed

at a temperature chosen in the range 200°C-400°C.

16. Method according to claim 15, characterized in that the heat treatment is performed at a temperature chosen in the range 300°C-350°C.

17. Method according to claim 15 or claim 16, characterized in that the heat treatment is conducted for approximately 2 hours to 5 hours.

18. Method according to claim 12, characterized in that the source substrate is prepared from a semiconductor material of type III-V.

19. Method according to claim 12, characterized in that the source substrate is prepared from an insulator chosen from the group consisting of $LiNbO_3$ and $LiTaO_3$.

20. Method according to any one of claims 1 to 19, characterized in that the first species is hydrogen.

21. Method according to claim 20, characterized in that the first species is hydrogen of H^+ type.

22. Method according to claim 21, characterized in that the first species is implanted at a dose of the order of few 10^{16} H/cm^2.

23. Method according to any one of claims 1 to 22, characterized in that the second species is helium.

24. Method according to claim 23, characterized in that the second species is implanted at a dose of the order of few 10^{16} He/cm^2, less than the dose of the first species.