

DESCRIPTION

TITLE OF INVENTION: METHOD FOR TRANSFERRING A THIN FILM TO A SUPPORT SUBSTRATE

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FIELD OF THE INVENTION

[0001] The present invention relates to the field of microelectronics and semiconductors. In particular, the invention relates to a method for transferring
10 a thin film onto a support substrate, based on Smart Cut™ technology, the thin film exhibiting improved roughness after separation. In particular, the transfer method can be used to manufacture an SOI structure.

TECHNOLOGICAL BACKGROUND OF THE INVENTION

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[0002] Smart Cut™ technology is well known for manufacturing SOI (silicon-on-insulator) structures and, more generally, for thin-film transfer. This technology is based on the formation of a brittle plane buried in a donor substrate, by implanting light species into said substrate; the buried brittle
20 plane delimits, with a front face of the donor substrate, the thin film to be transferred. The donor substrate and a support substrate are then joined at their respective front faces to form a bonded assembly. The assembly is advantageously carried out by direct bonding, by molecular adhesion, that is, without involving adhesive material: a bonding interface is thus established
25 between the two assembled substrates. Microcrack growth in the buried brittle plane, through thermal activation, can lead to spontaneous separation along said plane, resulting in the transfer of the thin film onto the support substrate (forming the stacked structure). The remaining donor substrate can be reused for a subsequent film transfer. After separation, it is usual to apply finishing
30 treatments to the stacked structure, to restore the crystalline quality and surface roughness of the transferred thin film. In particular, these finishing steps may involve oxidizing or smoothing heat treatments (in a neutral or

reducing atmosphere), chemical cleaning and/or etching and/or chemical-mechanical polishing steps, as is known to the person skilled in the art. Finally, various tools for inspecting the final structure enable the entire surface of the thin film to be checked.

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[0003] When separation in the buried brittle plane is spontaneous, significant variability is observed in terms of the surface roughness of the thin film transferred, both at high frequencies (microroughness) and at low frequencies (rippling, local areas of high roughness, mottling, etc.). These variabilities are visible and measurable in particular via the aforementioned inspection tools, when checking the thin film in the final structure.

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[0004] Recall that the surface roughness of the thin film after finishing can be mapped using a Surfscan™ inspection tool from KLA-Tencor ([Fig.1]). The level of roughness and potential patterns (mottling (M), dense areas (ZD), etc.) are measured or made apparent by measuring the diffuse background noise ("haze") corresponding to the intensity of the light scattered by the surface of the thin film. The haze signal varies linearly with the square of the RMS surface roughness (root-mean-square roughness) in the spatial frequency range from 0.1 μm^{-1} to 10 μm^{-1} . Please refer to the article "Seeing through the haze", by F. Holsteyns (Yield Management Solutions, Spring 2004, pp50-54) for more information on this large-area roughness inspection and evaluation technique.

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[0005] The maps in [Fig. 1] show the surface roughness of two thin films transferred from two bonded assemblies and treated identically up to the finishing. Map (A) shows a peripheral area of residual roughness, known as the "dense area (ZD)" (in particular, at the top of the map); map (B) is completely devoid of this area. More pronounced mottling (M) is also visible in map (A). The average and maximum roughnesses (expressed in ppm haze) are further significantly different between the two maps (A) and (B). [Fig.1] shows the variability of the final quality and roughness of thin films, which is

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mainly due to the variability of surface roughness (high and low frequencies) after separation.

5 [0006] To improve the quality of the thin films in the final stacked structure, it remains important to reduce the surface roughness (whatever the spatial frequency) of these layers after transfer.

10 [0007] It is known from US2010/330779 to form a local unbonded area at the bonding interface, bordered by a bonded region, to constitute a separation trigger and thus limit the roughness of a thin silicon layer transferred onto a glass support substrate. The local unbonded area is obtained by creating a topology corresponding to a cavity and/or dome (or peak) on the face of the donor substrate (silicon) or support substrate (glass) to be bonded. Cavities and/or peaks of the order of 2 to 3 micrometers are formed on the glass
15 substrate, to create an unbonded area of several tens of mm².

OBJECT OF THE INVENTION

20 [0008] The present invention proposes a transfer method using a particular fracture initiation point, enabling improved surface roughness of the thin film after separation, to achieve excellent surface quality after the finishing steps of the stacked structure. The method is particularly advantageous for the manufacture of SOI structures.

25 **BRIEF DESCRIPTION OF THE INVENTION**

[0009] The present invention relates to a method for transferring a thin film to a support substrate, comprising:

30 [0010] - assembling a donor substrate and the support substrate, by direct bonding at their respective front faces and following a bonding interface, to form a bonded assembly having a local unbonded area within this bonding interface, the donor substrate further comprising a buried brittle plane,

- separating along the buried brittle plane, initiated at the local unbonded area after microcrack growth in said plane by thermal activation, the separation resulting in the transfer of a thin film from the donor substrate to the support substrate.

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[0011] According to the invention, the local unbonded area is generated by at least one roughened area produced by scanning a laser beam over at least one of the front faces of the donor and support substrates prior to their assembly, the scanning extending over an area of at least 100 micrometers by 100 micrometers and at most 500 micrometers by 500 micrometers.

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[0012] According to advantageous features of the invention, taken alone or in any feasible combination:

- the roughened area is produced by surface fusion of a material making up the donor substrate and/or the support substrate, on the side of their respective front faces;

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- the laser beam scan has a duration of between 20 microseconds and 100 microseconds, during which the beam has an energy density of between 5 mJ/m² and 7 mJ/m²;

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- the laser beam has a wavelength of 355 nm.

- the laser beam has a size inscribed in a circle 80 micrometers in diameter;

- the local unbonded area is generated by a plurality of elementary roughened areas separated from one another, each produced by scanning the laser beam over an area of at least 100 micrometers by 100 micrometers and at most 200 micrometers by 200 micrometers;

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- the roughened area is formed on the front face of the donor substrate, before the formation of the buried brittle plane in said donor substrate;

- the donor substrate is formed from a first material on its front face, and a preliminary roughened area is formed on the surface of said material, and thermal oxidation of the first material of the donor substrate is carried out after formation of the preliminary roughened area and before formation of the buried brittle plane, to form an insulating layer that will be assembled on the support

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- substrate in the bonded assembly, said insulating layer comprising, on its free face, the roughened area plumb with the preliminary roughened area;
- the support substrate is formed from a first material on its front face, and a preliminary roughened area is formed on the surface of said material, and
- 5 thermal oxidation of the first material of the support substrate is carried out after formation of the preliminary roughened area, to form an insulating layer that will be assembled on the donor substrate in the bonded assembly, said insulating layer comprising, on its free face, the roughened area plumb with the preliminary roughened area;
- 10 - the local unbonded area has at least one lateral dimension, in the plane of the bonding interface, of less than 500 micrometers;
- the donor substrate and the support substrate have a disc shape with a diameter of 300 mm;
 - the local unbonded area is located at more than 3 mm from the edge of the
- 15 bonded assembly, in the plane of the bonding interface;
- the local unbonded area is located at less than 10 mm from the edge of the bonded assembly, in the plane of the bonding interface;
 - the transfer method further comprises a step of annealing the bonded assembly to cause separation along the buried brittle plane, this step being
- 20 carried out in a furnace by holding the bonded assembly there vertically and angularly oriented so as to place the roughened area in an upper portion of the furnace;
- the thin film from the donor substrate is monocrystalline silicon and the support substrate comprises monocrystalline silicon, to form a stacked SOI
- 25 structure.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0013] Other features and advantages of the invention will emerge from the
- 30 following detailed description of the invention with reference to the appended figures, in which:

[0014] [Fig.1] [Fig.1] shows two representative surface roughness maps of two transferred thin films, from two bonded assemblies processed identically until finishing, using a conventional method; both maps were obtained via a Surfscan™ inspection tool;

- 5 [0015] [Fig.2] [Fig.2] shows a graph indicating the surface roughness of thin films as a function of fracture time, for a plurality of bonded structures (of a different type from the bonded structures shown in reference to [Fig.1]) treated identically until finishing, according to a conventional method;

- 10 [0016] [Fig.3a] [Fig.3a] shows a bonded structure used in an intermediate stage of the transfer method according to the invention;

[0017] [Fig. 3b] [Fig. 3b] shows an example of a donor or support substrate comprising a roughened area deliberately formed on its front face, in accordance with the transfer method of the invention, which roughened area has a predetermined roughness;

- 15 [0018] [Fig.4] [Fig.4] shows a stacked structure and the remainder of a donor substrate, obtained by a transfer method in accordance with the invention;

[0019] [Fig.5] [Fig.5] shows images of the roughened area obtained according to a first example embodiment;

- 20 [0020] [Fig.6] [Fig.6] shows images of the roughened area obtained according to a second example embodiment;

[0021] [Fig.7] [Fig.7] shows images of preliminary roughened areas obtained according to a third example embodiment.

DETAILED DESCRIPTION OF THE INVENTION

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[0022] Some figures are schematic depictions which, for the sake of readability, are not to scale. In particular, the thicknesses of the layers along the z-axis are not to scale with respect to the lateral dimensions along the x- and y-axes.

- 30 [0023] The same references in the figures and in the description may be used for elements of the same type.

[0024] The invention relates to a method for transferring a thin film onto a support substrate, to form a stacked structure. As mentioned in the introduction, such a stacked structure can be of the SOI type, comprising a thin silicon surface layer, an intermediate insulating layer of silicon oxide and a silicon support substrate. The support substrate can optionally comprise other functional layers, such as a charge trapping layer (for example a surface layer of polycrystalline silicon), for example for SOI structures designed for radio frequency (RF) applications. The transfer method described here is not limited to the manufacture of SOI, however, and can be applied to many other stacked structures in the field of microelectronics, microsystems and semiconductors.

[0025] The transfer method according to the invention is based on Smart Cut™ technology. When separation in the buried brittle plane is spontaneous, the fracture time (that is the time after which separation occurs, during thermal fracture annealing) may differ between a plurality of identically treated bonded assemblies, undergoing the same annealing, in the same furnace. The fracture time (TF) depends on a multitude of parameters linked to the formation of the buried brittle plane, the fracture annealing, the nature of the bonded assembly, etc. The applicant has noted that, for similarly prepared bonded assemblies undergoing the same fracture annealing, separations occurring at short fracture times (TFc) result in thin films having lower high-frequency surface roughness (microroughness) in the final stacked structures (that is after transfer and finishing) than separations occurring at longer fracture times (TFI), as can be seen in [Fig.2]. Furthermore, long fracture times induce a local zone of very high roughness (called the dense area ZD) at the edge of the thin film after fracture, which is not the case or rarely so when the fracture time is short. This dense area degrades the quality and roughness of the thin film, even after finishing, as can be seen in map (A) in [Fig. 1].

[0026] The transfer method according to the invention therefore aims to initiate spontaneous separation in the buried brittle plane in an early (short fracture time) and repeatable (low fracture time dispersion between a plurality of similar

bonded assemblies) manner, so as to substantially improve the surface roughness of the transferred thin film.

[0027] To achieve this, the transfer method first comprises assembling a donor substrate 1 and the support substrate 2, by direct bonding at their respective front faces 1a, 2a and along a bonding interface 3, to form a bonded assembly 100 ([Fig. 3a]).

[0028] The donor substrate 1 is preferentially in the form of a wafer with a diameter of 100 mm, 150 mm, 200 mm, 300 mm or even 450 mm, and with a thickness typically between 250 μm and 1 mm. It comprises a front face 1a and a rear face 1b. The surface roughness of the front face 1a is chosen to be less than 1.0 nm RMS, preferentially even less than 0.5 nm RMS (measured by atomic force microscopy (AFM), for example on a 20 μm x 20 μm scan). The donor substrate 1 can be made of silicon or any other semiconducting or insulating material for which thin-film transfer may be of interest (e.g. SiC, GaN, III-V compounds, piezoelectric materials, etc.). It should also be noted that the donor substrate 1 may comprise one or more additional layers 12, at least on its front face 1a, such as an insulating layer. As shown in [Fig. 3a], this additional layer 12 becomes a buried intermediate layer in the bonded assembly 100, after assembly of the donor substrate 1 and the support substrate 2.

[0029] The donor substrate 1 comprises a brittle buried plane 11, which delimits a thin film 10 to be transferred. As is well known referring to the Smart Cut™ technology, such a buried brittle plane 11 can be formed by implanting light species, such as hydrogen, helium or a combination of both. The light species are implanted at a determined depth in the donor substrate 1, consistent with the thickness of the targeted thin film 10. These light species will form, around the determined depth, microcavities distributed in a thin film substantially parallel to the front face 1a of the donor substrate 1, or parallel to

the plane (x, y) in the figures. This thin film is called the buried brittle plane 11, for simplicity's sake.

[0030] The implantation energy of the light species is chosen so as to reach
5 the determined depth. For example, hydrogen ions will be implanted at an energy of between 10 keV and 210 keV, and at a dose of between $5E16/cm^2$ and $1E17/cm^2$, to delimit a thin film 10 having a thickness of the order of 100 to 1500 nm. Recall that an additional layer may be formed on the front face 1a of the donor substrate 1, prior to the ion implantation step. This additional layer
10 may be composed of a material such as silicon oxide or silicon nitride, for example. It can be retained for the next assembly step (and form all or part of the intermediate layer of the bonded assembly 100), or it can be removed.

[0031] The support substrate 2 is also preferentially in the form of a wafer with
15 a diameter of 100 mm, 150 mm, 200 mm, 300 mm or even 450 mm, and with a thickness typically between 250 μm and 1 mm. It comprises a front face 2a and a rear face 2b. The surface roughness of the front face 2a is chosen to be less than 1.0 nm RMS, preferentially even less than 0.5 nm RMS (measured by AFM, for example on a 20 μm x 20 μm scan). The support substrate 2 can
20 be made of silicon or any other semiconducting or insulating material for which thin-film transfer may be of interest (e.g. SiC, GaN, III-V compounds, piezoelectric materials, insulating materials, etc.). It should also be noted that the support substrate 2 may comprise one or more additional layers, at least on its front face 2a, for example an insulating and/or charge-trapping layer.
25 This (or these) additional layer(s) is (are) buried in the bonded assembly 100, after assembly of the donor substrate 1 and the support substrate 2.

[0032] The assembly between the donor substrate 1 and the support substrate 2
is based on direct bonding by molecular adhesion. As is well known per se, such
30 bonding does not require an adhesive material, as atomic-scale bonds are established between the joined surfaces, forming the bonding interface 3. Several types of molecular adhesion bonding exist, which differ in particular by their

temperature, pressure, atmosphere conditions or treatments prior to contacting the surfaces. Mention may be made of bonding at room temperature with or without prior plasma activation of the surfaces to be assembled, atomic diffusion bonding (ADB), surface-activated bonding (SAB), etc.

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[0033] The assembly step may comprise, before the contacting of the front faces 1a, 2a to be assembled, conventional chemical cleaning sequences (for example, RCA cleaning), surface activation (for example, oxygen or nitrogen plasma) or other surface preparations (such as cleaning by scrubbing),
10 capable of promoting the quality of the bonding interface 3 (few defects, strong adhesion energy).

[0034] The bonded assembly 100 according to the invention has the particularity of comprising a local unbonded area 31 within the bonding
15 interface 3 ([Fig. 3a]). In other words, this local unbonded area 31 is bordered by the bonding interface 3, which is closed, reflecting the molecular adhesion forces uniting the front faces 1a, 2a of the assembled substrates 1, 2.

[0035] The local unbonded area 31 is generated solely by the presence of a
20 roughened area 31a, deliberately created on at least one of the front faces 1a, 2a of the donor 1 and support 2 substrates, prior to their assembly ([Fig. 3b]). The roughened area 31a is free of any low-frequency topology or ripple, that is, with a typical wavelength greater than 100 nm. It has a predetermined high-frequency roughness, which is greater than the roughness of the front faces
25 1a, 2a around this roughened area 31a. The roughness of the front faces 1a, 2a can typically vary based on the nature of the materials of said faces 1a, 2a and based on the type of direct bonding implemented, but it always enables a bonded (closed) interface to be obtained, whereas the predetermined roughness in the roughened area 31a prevents local bonding between the two
30 faces 1a, 2a.

[0036] The amplitude of the predetermined roughness is strictly greater than 0.5 nm RMS and strictly less than 60.0 nm RMS, with typical wavelengths between 10 nm and 100 nm (corresponding to high-frequency microroughness). As is well known, the term RMS ("root mean square") corresponds to a root-mean-square roughness value. The technique used to measure this microroughness is atomic force microscopy (AFM), on scans from 10x10 μm^2 to 30x30 μm^2 . It should be recalled that the roughened area 31a does not have a topology that would correspond to a low-frequency ripple, but only a microroughness in the spatial frequency range stated above. The maximum peak-to-valley (PV) amplitude in the roughened area 31a is typically between 5.0 nm and 300.0 nm, preferentially between 5.0 nm and 100.0 nm. In particular, in the example shown in [Fig. 3b], the roughened area 31a has a roughness of 2.3 nm RMS and 25 nm PV, measured by AFM on a 10 μm x 10 μm scan (image on the right in [Fig. 3b]).

[0037] According to a particular embodiment used in particular for the manufacture of SOI structures, the front face 1a, 2a, whereupon the roughened area 31a is produced, is made of monocrystalline silicon, and the predetermined roughness preferentially has an amplitude of between 5 nm RMS and 15 nm RMS, and still more preferentially, this amplitude is between 9 nm RMS and 12 nm RMS.

[0038] However, the invention is by no means limited to the formation of the roughened area 31a on a front face made of monocrystalline silicon and, in an alternative, the face on which the roughened area 31a is formed is made of polycrystalline silicon.

[0039] Note that, when the front face 1a the donor substrate 1 carries the roughened area 31a, the latter is preferentially produced before the formation of the buried brittle plane 11 in said substrate 1, to limit any damage or premature ripening of the microcavities composing it.

[0040] It is also possible to create a preliminary roughened area on a first material forming the donor substrate 1, on its front face; for example, the first material could be silicon. The first material of the donor substrate 1 is then thermally oxidized to form an insulating layer (e.g. silicon oxide). The thickness of the insulating layer may, for example, be less than or equal to 200 nm. Said insulating layer (corresponding to the additional layer 12 shown in [Fig. 3a]) comprises, on its free face (the front face 1a of the donor substrate 1), the roughened area 31a plumb with the preliminary roughened area developed in the first material. In fact, oxidation preserves at least part of the high-frequency roughness of the first material in the preliminary roughened area: the aim is to form a microroughness in the preliminary roughened area capable of giving rise to a predetermined roughness of the roughened area 31a after oxidation, in the aforementioned range of amplitudes. After formation of the buried brittle plane 11 in the donor substrate 1, the insulating layer 12 is assembled on the support substrate 2 in the bonded assembly 100, and the roughened area 31a generates the local unbonded area 31 within the bonding interface 3. In this case, the roughened area 31a on the front face 1a of the donor substrate 1 has not been produced directly by "roughening" the insulating layer 12, but is derived from a preliminary roughened area present in an underlying material.

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[0041] For the sake of thoroughness, it will be noted that although the formation of this preliminary roughened area has been disclosed with reference to the donor substrate 1, it could of course be applied to the support substrate 2.

[0042] Once the bonded assembly 100 has been formed and comprises the local unbonded area 31 within its bonding interface 3, the transfer method according to the invention involves applying thermal annealing to it, which will give rise to spontaneous separation along the buried brittle plane 11. Separation leads to the transfer of the thin film 10 from the donor substrate 1 to the support substrate 2, to form the stacked structure 110 ([Fig.4]). A non-transferred area 31b, to which the thin film 10 has not been transferred, is present plumb with the location of the local unbonded area 31. This non-

transferred area 31b may be equal to or larger than the size of the local unbonded area 31. The remainder of the donor substrate 1' is also obtained.

[0043] The local unbonded area 31 acts as a fracture initiation point, in the buried brittle plane 11 and at or proximate to said area 31, after microcrack growth in the buried brittle plane 11 by thermal activation. This fracture initiation occurs earlier than with a bonded assembly 100 that does not comprise the local unbonded area 31: this gives access to short fracture times, which provide low surface roughness, after transfer, on the face 10a of the thin film 10. Note will be made of a clear improvement in surface roughness after transfer, due to the short fracture times obtained owing to the local unbonded area 31, which acts as a fracture initiation point.

[0044] The local unbonded area 31 according to the invention differs from the prior art in that it is due solely to the presence of a roughened area 31a on the front face 1a, 2a of one or other of the donor substrate 1 and support substrate 2. No low-frequency topology is involved (bumps, holes, cavities, particles). The internal volume of the local unbonded area 31 thus created is extremely small; in fact, the accumulation, in this internal volume, of various gases resulting in particular from the vaporization of the water monolayers present on the bonded faces 1a, 2a or from the exo-diffusion of light species by the front face 1a of the donor substrate 1 enables rapid pressurization favorable to fracture initiation as soon as the level of ripening of the microcracks in the buried brittle plane 11 allows it.

[0045] The local unbonded area 31 can be located at various positions in the plane of the bonding interface 3: in particular, in a central region of the bonded assembly 100 or in a peripheral region or even in an intermediate region between these two extremes. In the peripheral region, it is preferable for the local unbonded area 31 to be more than 3 mm from the edge of the bonded assembly 100.

[0046] Preferably, especially when the bonded assembly 100 has a thick layer 12 of more than 100 nm, the local unbonded area 31 should be less than 10 mm from the edge of the bonded assembly 100, in the plane of the bonding interface 3.

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[0047] Advantageously, a step of annealing the bonded assembly 100 is applied to cause separation along the buried brittle plane 11. Conventionally, this step is carried out in a furnace, where the bonded assembly 100 is held vertically. Advantageously, the bonded assembly 100 is angularly oriented in the furnace chamber so as to place the roughened area 31a in an upper portion of the furnace. This upper portion generally has a higher temperature, which favors fracture initiation at the roughened area 31a.

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[0048] To avoid penalizing the transfer integrity of the thin film 10, the local unbonded area 31 advantageously has at least one lateral dimension, in the (x,y) plane, of less than 500 micrometers.

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[0049] According to the invention, the roughened area 31a is produced by scanning a laser beam over at least one of the front faces 1a, 2a of the donor 1 and support 2 substrates before they are assembled. This scan extends over an area of at least 100 micrometers by 100 micrometers and at most over an area of 500 micrometers by 500 micrometers. Put another way, the scanned surface circumscribes an area measuring 100 micrometers by 100 micrometers and is inscribed in an area measuring 500 micrometers by 500 micrometers. This approach is advantageous in that it makes it possible to form this roughened area with as little contact as possible with the rest of the concerned front face 1a, 2a, so as to reduce the risk of contamination or degradation (scratches, etc.) of this face, which is to be assembled. The beam is scanned via movable optical parts (a scanner), such as a set of mirrors, to keep the substrate stationary while treating a relatively large surface area, that is to say larger than the beam size. It can therefore be of reduced size, for example inscribed in a circle 80 micrometers in diameter. In one embodiment,

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the laser beam has a rectangular shape measuring 70 micrometers by 40 micrometers.

[0050] The laser beam parameters are chosen to generate only surface melting of the front face material 1a, 2a, and only in the area to be roughened. This therefore constitutes a melting limit regime, and not at all ablation regimes that remove material or hollow it out. This regime corresponds to "discontinuous" melting of the irradiated surface, which means that melted and unmelted areas are induced on the surface, conducive to the formation of the desired high-frequency roughness. If the energy density is too low, melting cannot be achieved and little or no roughness is generated; if the energy density is too high, "homogeneous" melting of the entire irradiated surface takes place, with uniform recrystallization and potentially too little roughness. It is therefore important to be in the melting limit regime, to generate high-frequency roughness of the expected amplitude, and not to create any topology, cavities or bumps, only high-frequency roughness, in the RMS and PV ranges mentioned above.

[0051] Preferentially, the laser beam scanning is therefore done for a duration of between 20 microseconds and 100 microseconds, during which the beam has an energy density of between 5 mJ/m² and 7 mJ/m². The wavelength of the laser used can be chosen between 100 nm and 550 nm, preferably between 250 nm and 400 nm, such as 355 nm for example.

[0052] The roughened area 31a generated, after laser beam scanning, is substantially smaller than the size of the irradiated surface. This is due in particular to the fact that the energy density is not constant over the entire beam projection surface, and tends to be lower on its peripheral contour. Thus, when the beam scans a large area, up to 500 micrometers by 500 micrometers, the roughened area is smaller and included in the scanned area.

[0053] Note that in the case where the material of the front face 1a, 2a is a silicon oxide and the underlying material is silicon, the laser scanning passes through the silicon oxide layer and will generate melting of the silicon, which will induce the formation of wrinkles on the oxide surface. These wrinkles form the expected high-frequency roughness, in the irradiated region, on the front face 1a, 2a.

[0054] The local unbonded area 31 may be generated by a plurality of elementary roughened areas 31a that are close to but separated from one another, for example between 2 and 5 elementary roughened areas 31a. Each elementary roughened area is produced by scanning the laser beam over an area of at least 100 micrometers by 100 micrometers and at most 200 micrometers by 200 micrometers, so that the local unbonded area 31 remains small overall.

[0055] The shapes of the roughened area 31a and the local unbonded area 31 are not necessarily square. They can, for example, be rectangular or of any other shape, as long as the laser beam is scanned over an area of at least 100 micrometers by 100 micrometers and at most 500 micrometers by 500 micrometers.

Example embodiment:

[0056] According to a first example, the transfer method is used to produce an FDSOI (fully depleted SOI) structure, that is, with a thin surface film (for example in the range from 10 nm to 50 nm) and a thin buried insulating layer (for example in the range from 15 nm to 25 nm).

[0057] The donor substrate 1 is a single-crystal silicon wafer with a diameter of 300 mm, and comprises a 35nm-thick insulating layer 12 of silicon oxide on its front face 1a. The buried brittle plane 11 is formed by co-implantation of

helium and hydrogen ions at energies of 40 keV and 25 keV, respectively, and at doses of between 0.8 E16/cm^2 and 1.8 E16/cm^2 , respectively.

5 [0058] The support substrate 2 is a monocrystalline silicon wafer with a diameter of 300 mm.

[0059] The laser beam scanning is done at the center of the support substrate 2, on the side of its front face 2a, so as to cause melting/recrystallization of the surface only, in a melting limit regime. The laser conditions are as follows:
10 wavelength 355 nm, the laser irradiates the surface for 50 μs and with an energy density of 6.3 mJ/cm^2 , the size of the irradiated surface is $100 \mu\text{m}$ square. These conditions therefore lead to the formation of a roughened area within the irradiated surface, with an RMS roughness of $11 \text{ nm} \pm 0.5 \text{ nm}$, measured by AFM on a $30 \mu\text{m}$ by $30 \mu\text{m}$ scan (see, for example, the SEM
15 image on the left of [Fig.5] and the optical mode image on the right of [Fig.5]).

[0060] A conventional surface preparation (cleaning, plasma activation) of the two substrates 1, 2 is then carried out with a view to molecular adhesion bonding.

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[0061] Assembly, based on direct contact between the front faces 1a, 2a of the donor substrate 1 and the support substrate 2, produces a bonded assembly 100. The bonded assembly 100 comprises a local unbonded area 31 plumb with the roughened area 31a (at the center of the bonded assembly 100),
25 within the bonding interface 3. The local unbonded area 31 has a size of $40 \mu\text{m}$ by $60 \mu\text{m}$.

[0062] Fracture annealing, done in a horizontal furnace (suitable for treating a plurality of bonded assemblies 100 collectively), is applied between 200°C and
30 400°C . The local unbonded area 31 enables fracture to be initiated along the buried brittle plane 11 in a short time, that is, around 25% of the average fracture time in the absence of the local unbonded area 31, in the case of

isothermal annealing. By considering a plurality of collectively treated bonded assemblies 100, the local unbonded area 31 further makes it possible to obtain less dispersed fracture times.

5 [0063] The SOI structure 110 obtained after separation has a non-transferred area 31b in place of the local unbonded area 31 of the bonded assembly 100, and whose size is of the order of 100 micrometers to 200 micrometers. The surface quality 10a of the transferred thin film 10 is improved compared with
10 an SOI 110' structure obtained from a conventional bonded assembly, without a local unbonded area 31. This is particularly visible after the application of finishing steps (mainly oxidation and smoothing heat treatments) to heal the transferred thin film 10 and smooth its surface: SOI structures 110 obtained by the method of the invention do not show dense areas of roughness at the periphery of the thin film 10, unlike certain SOI structures 110' obtained by a
15 conventional method (without local unbonded areas 31).

[0064] In a second example, the transfer method is used to produce an RFSOI (SOI for radio frequency applications) structure, that is, a thin surface film, an insulating layer and a charge trapping layer on the support substrate 2.

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[0065] The donor substrate 1 is a single-crystal silicon wafer with a diameter of 300 mm, and comprises a 200nm-thick insulating layer 12 of silicon oxide on its front face 1a. The buried brittle plane 11 is formed by co-implantation of hydrogen and helium ions at energies of 35 keV and 50 keV, respectively, and
25 at doses of between 0.8 E16/cm^2 and 1.8 E16/cm^2 , respectively. The support substrate 2 is a monocrystalline silicon wafer with a diameter of 300 mm. A polycrystalline silicon charge trapping layer, approximately $1 \text{ }\mu\text{m}$ thick, is arranged on the front face 2a side of the support substrate 2.

30 [0066] Laser scanning is carried out in a peripheral region of the donor substrate 1, between 3 and 10 mm from the edge of the donor substrate 1, on the side of its front face 1a, so as to cause surface melting/recrystallization

only. This treatment is carried out prior to the formation of the buried brittle plane 11.

5 [0067] The laser scanning conditions are as follows: wavelength 355 nm, scanning time 30 μ s, energy density 6.3 mJ/cm², irradiated surface square with a side length of 200 micrometers. Laser scanning therefore leads to the formation of a roughened area at the irradiated surface, with an RMS roughness of 9 nm +/- 0.5 nm, measured by AFM on a scan of 30 μ m by 30 μ m. The roughened area is shown in [Fig.6] (SEM image on the left, optical
10 mode on the right).

[0068] A conventional surface preparation (cleaning, plasma activation) of the two substrates 1, 2 is then carried out with a view to molecular adhesion bonding. Assembly, based on direct contact between the front faces 1a, 2a of
15 the donor substrate 1 and the support substrate 2, produces a bonded assembly 100. The bonded assembly 100 comprises a local unbonded area 31 plumb with the roughened area 31a (at the edge of the bonded assembly 100), within the bonding interface 3. The local unbonded area 31 has a size of between 140 μ m and 170 μ m.

20 [0069] Fracture annealing, carried out in a horizontal furnace (suitable for treating a plurality of bonded assemblies 100 collectively arranged vertically in the furnace chamber), is applied at between 200°C and 550°C. The bonded assemblies are angularly oriented in the furnace chamber so that the
25 roughened area 31a is located in an upper position of the furnace chamber.

[0070] The local unbonded area 31 enables fracture to be initiated along the buried brittle plane 11 in a short time (around 30% of the average fracture time without the local unbonded area 31). By considering a plurality of collectively
30 treated bonded assemblies 100, the local unbonded area 31 further makes it possible to obtain less dispersed fracture times. The SOI structure 110 obtained after separation has a non-transferred area in place of the local

unbonded area 31 of the bonded assembly 100, and whose size is between 250 and 350 μm .

[0071] The surface quality 10a of the transferred thin film 10 is improved compared with an SOI 110' structure obtained from a conventional bonded assembly, without a local unbonded area 31. This is particularly visible after the application of finishing steps (mainly oxidation and smoothing heat treatments) to heal the transferred thin film 10 and smooth its surface: the map in [Fig. 6] of the SOI structure 110 obtained by the method of the invention shows an absence of dense areas of roughness at the periphery of the thin film 10, unlike the SOI structure 110' obtained by a conventional method (without local unbonded areas 31); it also shows a lower overall level of roughness over the entire surface of the thin film 10 of the SOI structure 110.

[0072] In a third example, the transfer method is used to produce an SOI structure, that is, having a thin surface film, an insulating layer and a support substrate 2. The donor substrate 1 is a monocrystalline silicon wafer with a diameter of 300 mm.

[0073] Three successive scans of the laser beam are done in a central or peripheral region of the donor substrate 1, on the side of its front face 1a (therefore on the silicon), so as to cause melting/re-crystallization of the surface only. Three roughened areas are thus created, which are separated by a distance of 80 micrometers. The laser conditions are as follows: wavelength 355 nm, duration of each scan of the beam 30 μs , energy density 6.3 mJ/cm^2 , each irradiated surface is square with a side length of 100 μm . These scans lead to the formation of preliminary roughened areas at the irradiated surface, with an RMS roughness greater than 11 nm ± 0.5 nm, measured by AFM on a scan of 30 μm by 30 μm . These preliminary roughened areas are shown in [Fig.7] (left image in optical mode of the 3 scanned areas and, on the right, a zoom in SEM mode on one of the scans).

[0074] After standard cleaning of the donor substrate 1, thermal oxidation is carried out, typically in the 900°C - 1050°C temperature range. After this oxidation, the front face 1a of the donor substrate 1 comprises an insulating layer 12 of silicon oxide measuring 200 nm thick. Plumb with the 3 preliminary roughened areas, 3 roughened areas 31a are present on the free face 1a of the insulating layer 12. These roughened areas 31a have an RMS roughness substantially identical to that of the preliminary roughened areas.

[0075] The buried brittle plane 11 is formed by co-implantation of hydrogen and helium ions at energies of 35 keV and 50 keV, respectively, and at doses of between 0.8 E16/cm² and 1.8 E16/cm², respectively, through the insulating layer 12, in the donor substrate 1. The support substrate 2 is a monocrystalline silicon wafer with a diameter of 300 mm.

[0076] A conventional surface preparation (cleaning, plasma activation) of the two substrates 1, 2 is then carried out with a view to molecular adhesion bonding. Assembly, based on direct contact between the front faces 1a, 2a of the donor substrate 1 and the support substrate 2, produces a bonded assembly 100. The bonded assembly 100 comprises a local unbonded area 31 plumb with the roughened area 31a, within the bonding interface 3. Fracture annealing, performed in a horizontal furnace (suitable for treating a plurality of bonded assemblies 100 collectively), is applied at between 200°C and 550°C. The local unbonded area 31 allows fracture to be initiated along the buried brittle plane 11 in a short time (around 30% of the average fracture time without local unbonded area 31). By considering a plurality of collectively treated bonded assemblies 100, the local unbonded area 31 makes it possible to obtain less dispersed fracture times.

[0077] The SOI structure 110 obtained after separation has a non-transferred area in place of the local unbonded area 31 of the bonded assembly 100, and whose size is typically less than 500 µm.

[0078] The surface quality 10a of the transferred thin film 10 is improved compared with an SOI structure 110' obtained from a conventional bonded assembly, without a local unbonded area 31: it shows an absence of dense area ZD of roughness at the periphery of thin film 10, as well as a lower overall
5 level of roughness over the entire surface of the thin film 10.

[0079] Of course, the invention is not limited to the described embodiments and variant embodiments may be envisaged without departing from the scope of the invention as defined by the claims.

10

Claims

[Claim 1] A method for transferring a thin film (10) to a support substrate (2), comprising:

5 - assembling a donor substrate (1) and the support substrate (2), by direct bonding at their respective front faces (1a, 2a) and following a bonding interface (3), to form a bonded assembly (100) having a local unbonded area (31) within this bonding interface (3), the donor substrate (1) further comprising a buried brittle plane (11),

10 - separating along the buried brittle plane (11), initiated at the local unbonded area (31) after microcrack growth in said plane (11) by thermal activation, the separation resulting in the transfer of a thin film (10) from the donor substrate (1) to the support substrate (2),

 the method being **characterized in that** the local unbonded area (31) is generated by at least one roughened area (31a) produced by scanning a laser beam over at least one of the front faces (1a, 2a) of the donor (1) and support (2) substrates prior to their assembly, the scanning extending over an area of at least 100 micrometers by 100 micrometers and at most 500 micrometers by 500 micrometers.

20

[Claim 2] The transfer method according to the preceding claim, wherein the roughened area is produced by surface fusion of a material making up the donor substrate (1) and/or the support substrate (2), on the side of their respective front faces (1a, 2a).

25

[Claim 3] The transfer method according to the preceding claim, wherein the laser beam scan has a duration of between 20 microseconds and 100 microseconds, during which the beam has an energy density of between 5 mJ/m² and 7 mJ/m².

30

[Claim 4] The transfer method according to the preceding claim, wherein the laser beam has a wavelength of 355 nm.

[Claim 5] The transfer method according to one of the preceding claims, wherein the laser beam has a size inscribed in a circle 80 micrometers in diameter.

5

[Claim 6] The transfer method according to one of the preceding claims, wherein the local unbonded area (31) is generated by a plurality of elementary roughened areas (31a) separated from one another, each produced by scanning the laser beam over an area of at least 100 micrometers by 100 micrometers and at most 200 micrometers by 200 micrometers.

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[Claim 7] The transfer method according to one of the preceding claims, wherein the roughened area (31a) is produced on the front face (1a) of the donor substrate (1), prior to the formation of the buried brittle plane (11) in said donor substrate (1).

15

[Claim 8] The transfer method according to the preceding claim, wherein:

- the donor substrate (1) is formed from a first material on its front face (1a), and a preliminary roughened area is formed on the surface of said material, and

20

- thermal oxidation of the first material of the donor substrate (1) is carried out after formation of the preliminary roughened area and before formation of the buried brittle plane (11), to form an insulating layer that will be assembled on the support substrate (2) in the bonded assembly (100), said insulating layer comprising, on its free face, the roughened area (31a) plumb with the preliminary roughened area.

25

[Claim 9] The transfer method according to one of claims 1 to 6, wherein:

- the support substrate (2) is formed from a first material on its front face (2a), and a preliminary roughened area is formed on the surface of said material, and

30

- thermal oxidation of the first material of the support substrate (2) is carried out after formation of the preliminary roughened area, to form an insulating layer that will be assembled on the donor substrate (1) in the bonded assembly (100), said insulating layer comprising, on its free face, the roughened area (31a) plumb with the preliminary roughened area.

[Claim 10] The transfer method according to one of the preceding claims, wherein the local unbonded area (31) has at least one lateral dimension, in the plane of the bonding interface (3), of less than 500 micrometers.

10

[Claim 11] The transfer method according to one of the preceding claims, wherein the donor substrate (1) and the support substrate (2) have a disc shape with a diameter of 300 mm.

15 [Claim 12] The transfer method according to one of the preceding claims, wherein the local unbonded area (31) is located at more than 3 mm from the edge of the bonded assembly (100), in the plane of the bonding interface (3).

[Claim 13] The transfer method according to the preceding claim, wherein the local unbonded area (31) is located at less than 10 mm from the edge of the bonded assembly (100), in the plane of the bonding interface (3).

20 [Claim 14] The transfer method according to one of the two preceding claims, further comprising a step of annealing the bonded assembly (100) to cause separation along the buried brittle plane (11), this step being carried out in a furnace by holding the bonded assembly (100) there vertically and angularly oriented so as to place the roughened area (31a) in an upper portion of the furnace.

25 [Claim 15] The transfer method according to one of the preceding claims, wherein the thin film (10) from the donor substrate (1) is monocrystalline silicon

and the support substrate (2) comprises monocrystalline silicon, to form a stacked SOI structure (110).