

A METHOD FOR TRANSFERRING A USEFUL LAYER

FIELD OF THE INVENTION

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The present invention relates to a method for transferring a useful layer.

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TECHNOLOGICAL BACKGROUND OF THE INVENTION

A method for transferring a useful layer 3 onto a support substrate 4 is known from document FR3020175, as shown in Figure 1, with such method including the following main steps:

- 15 - in a step a), forming an embrittlement plane 2 by implanting light species into a first substrate 1, so as to form a useful layer 3 between such plane and one surface of the first substrate 1;
- 20 - in a step b), applying the support 4 onto the surface of the first substrate 1 so as to form an assembly to be fractured 5 having two exposed surfaces S1, S2;
- 25 - in a step c), applying a heat treatment for embrittling the assembly to be fractured 5;
- in a step d), initiating and propagating a fracture wave into the first substrate 1 along the embrittlement plane 2.

According to this document, acoustic vibrations are emitted upon the initiation and/or the propagation of the fracture wave. The interaction between the fracture wave and such acoustic vibrations, results in the forming of periodical patterns of variation in the thickness of the formed useful layer, which extend on the whole surface of the layer. In other words, the fracture wave is vertically deviated relative to the progression plane thereof, according to the state of the instantaneous stress of the material it goes through, with such stress state being affected by the acoustic wave. Figure 2 thus shows the patterns of variation in the thickness of the

useful layer transferred according to the method disclosed above. In the illustrated example, the patterns comprise side and circular patterns (respectively indicated by a and b in this Figure). Such patterns have been made apparent by measuring the "haze", as per the current English terminology, corresponding to the intensity of light broadcast by the layer surface, using the inspection tool Surfscan™ by the KLA-Tencor company. Reference can be made to the article « Seeing through the haze », by F. Holsteyns, Yield Management Solution, Spring 2004, pp50-54 for further information on such inspection technique.

To solve this problem, the above document provides to equip the assembly to be fractured with an absorbing element for detecting and dissipating the emitted acoustic wave, and preventing or limiting the formation of such patterns of variation in the thickness of the useful layer. Although this method is perfectly efficient, it nevertheless requires the implementation of one absorbing element on at least one of the faces of the assembly to be fractured, which makes the method for transferring the useful layer more complex.

OBJECT OF THE INVENTION

One aim of the invention consists in providing for a simple method for transferring a useful layer, with such useful layer having a pattern of variation in the thickness with a reduced extent.

BRIEF DESCRIPTION OF THE INVENTION

To reach this goal, the invention provides for a method for transferring a useful layer onto a support comprising the following steps of:

- forming an embrittlement plane by implanting light species into a first substrate, so as to form a useful

layer between such plane and one surface of the first substrate;

- applying the support onto the surface of the first substrate so as to form an assembly to be fractured;
- 5 - applying a heat treatment for embrittling the assembly to be fractured;
- initiating and propagating a fracture wave into the first substrate along the embrittlement plane.

10 The method is characterized in that the fracture wave is initiated in a central area of the embrittlement plane and the propagation speed of such wave is controlled so that the velocity thereof is sufficient. Thus, the interactions of the fracture wave with acoustic vibrations emitted upon the
15 initiation and/or propagation thereof are limited to a peripheral area of the useful layer 3.

 The invention makes it possible to limit the forming of periodical patterns of variation in the thickness to one part
20 only of the useful layer.

 According to other advantageous and not restrictive characteristics of the invention, taken either separately or
25 in any technically feasible combination:

- the propagation speed of the fracture wave is controlled so as to have a velocity higher than one third of the speed of the acoustic wave;
- 30 • the first substrate is made of silicon, and the propagation of the fracture wave is controlled so as to have a velocity above 2km/sec;
- 35 • the propagation of the fracture wave is controlled so as to have a velocity ranging from 2km/sec to 4.5km/sec; preferably from 3.8km/sec to 4.2km/sec;

- the fracture wave is initiated by applying the embrittlement heat treatment and the propagation speed is controlled by selecting the temperature of such heat treatment upon the initiation;

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- the temperature of the embrittlement heat treatment is above 400°C, or 500°C;

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- the initiation of the fracture wave is caused by an incipient fracture positioned in the central area of the embrittlement plane, or in the vicinity of such central area;

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- the incipient fracture consists of a volume containing light species in excess as compared to the average concentration in the embrittlement plane;

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- the incipient fracture consists of a cavity or a body positioned at the interface between the first substrate and the support in line with the central area of the embrittlement plane;

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- the fracture wave is initiated by energy input at the central area of the embrittlement plane;

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- the propagation speed is controlled by calibrating the embrittlement heat treatment so that the embrittlement plane has a maturing rate at least equal to a target maturing rate;

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- the first substrate consists of a disk-shaped wafer, and the central area comprises the geometric center of the wafer;
- the peripheral area consists of an annular area, the inner radius of circle of which is greater than $\frac{2}{3}$, and preferably greater than 80%, of the radius of the first substrate;

- the peripheral area is totally encompassed in one exclusion area of the useful layer.

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BRIEF DESCRIPTION OF THE DRAWINGS

Further characteristics and advantages of the invention will be clear from the detailed description of the invention,
10 made in reference to the appended figures, among which:

- Figure 1 shows a method for transferring a useful layer according to the state of the art;
- 15 - Figure 2 shows a view of the haze emitted by a useful layer of the prior art showing the periodical patterns of variation in the thickness;
- Figure 3 shows a diagram of the experimental relationship between the speed of the fracture wave and
20 the speed of the acoustic wave;
- Figure 4 shows a method for transferring a useful layer according to the invention;
- 25 - Figure 5a shows a view of the haze emitted by a useful layer obtained by a method according to the invention;
- Figure 5b shows a view of a useful layer obtained by a
30 simulation of a method according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

35 The inventors of the present application have thoroughly studied the phenomena disclosed in the presentation of the prior art to provide an original method for transferring a useful layer. This original approach does not

aim at limiting the development of the acoustic wave, for instance by collecting it and/or by absorbing it, but at limiting the interaction thereof with the fracture wave. The forming of the periodical patterns of variation in the thickness is thus limited to one part only of such layer.

The inventors thus noted that the acoustic wave would propagate from a fracture initiation point, at a speed higher than that of the fracture wave, and that the origin of the wave pattern originated from the interferences caused by the collision between the fracture wave and the reflection, on the ends of the assembly to be fractured, of the acoustic wave. The propagation characteristics of the acoustic wave, and specifically the speed thereof, can be measured by piezoelectric sensors positioned on one and/or the other faces of the assembly to be fractured.

To limit such interferences, the invention provides, on the one hand, to place the point of initiation of the fractures away from the ends of the assembly to be fractured, i.e. to place such point of initiation at a distance from the substrate edges, at a central area of the embrittlement plane. Thus, the moment when the reflected acoustic wave meets the fracture wave is delayed relative to the fracture initiation time.

Simultaneously, the invention provides to control the speed of propagation of the fracture wave. The latter is selected to be high enough for the area where the fracture wave and the reflected acoustic wave (which will have the periodical patterns of the variation in thickness of the useful layer) to be confined to a peripheral area of the assembly to be fractured. In the most advantageous situations, specifically if the speed of the fracture wave is high enough, the peripheral area can be encompassed in one exclusion area of the useful layer, i.e. an area where forming components is not planned, in general. Such exclusion area may be 0.5 to 2 or 3 millimeters, at the periphery of the useful layer. The

surface of the useful layer not encompassed within the peripheral area is mainly free of periodical patterns and thus has the required characteristics as regards thickness uniformity.

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It should be noted that the principle of the invention is based on the assumption, checked by the inventors of the present application, that the speed of propagation of the acoustic wave has no direct (for instance proportional) link
10 with the speed of propagation of the fracture wave.

As a matter of fact, if an assembly to be fractured having a circular shape and a radius R, is considered and Vg indicates the speed of the acoustic wave in the plane defined
15 by the assembly to be fractured and Vf is the speed of the fracture wave, then the distance d between the center of the assembly to be fractured (where the fracture is initiated from) and the place where both waves collide meets the following equation:

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$$d/V_f = (2R - d) / V_g$$

assuming that, at the meeting point, the fracture wave has travelled on a distance d, at a speed Vf, and the
25 reflected acoustic wave has travelled on a distance (2R-d) at a speed Vg. It can thus be determined that such distance d satisfies the following equation:

$$d = 2R / (1 + V_g / V_f)$$

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It can thus be noted that such distance d can be so controlled as to be as close to R as possible, insofar as the Vg/Vf ratio can be controlled too, to be close to 1.

Figure 3 shows results of experiments carried out by the inventors as a preparation of the present invention, showing the Vg/Vf ratio for various speeds Vf of the fracture
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wave. Such measures have been obtained when the method for transferring a layer is applied to a first silicon substrate.

5 It can be noted that the V_g/V_f ratio can be selected from a wide range from 1 to 2, by selecting the value of the fracture wave speed V_f . For a low speed of the fracture wave, of the order of 1km/sec, the speed of the acoustic wave is almost twice as high (V_g/V_f close to 2). Therefore, the meeting area is an annular area, the inner radius of which is
10 equal to $2/3$ of the radius R of the assembly to be fractured.

For a high speed of the fracture wave, the speed of the acoustic wave is slightly higher than that of the fracture wave (V_g/V_f close to 1). The meeting area is then limited to
15 an annular area, the inner radius of which is very close to the radius R of the assembly to be fractured, and so almost non existent.

20 On the basis of the study, the invention provides for a method for transferring a useful layer 3 onto a support 4 comprising the steps as shown in Figures 4a to 4d.

In a first step a), as shown in Figure 4a, an
25 embrittlement plane 2 is formed, for instance by implanting light species into the first substrate 1. The first substrate 1 may be made of silicon, or any other material, whether semi-conductive or not. It may be germanium, for instance, or gallium nitride, lithium tantalate, or sapphire. Layers can be
30 deposited beforehand, onto the surface, using a deposition or a heat treatment. It may be a layer made of silicon dioxide, obtained by thermal oxidation of a silicon board or a layer obtained by any kind of epitaxial deposition: SiGe; InGaN; AlGaN, Ge, etc.

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The first substrate 1 may be a disk-shaped wafer, with standard dimensions, for instance 200mm or 300mm, or even

450mm in diameter. However, the invention is in no way restricted to these dimensions or this shape.

5 As for the light species, these may be any species able to embrittle the first substrate 1 at the embrittlement plane thereof. It may be hydrogen and/or helium.

10 The embrittlement plane 2 defines, with a surface of the first substrate, the useful layer 3.

In a second step b), a support 4 is applied onto the surface of the first substrate 1 so as to form an assembly to be fractured 5. The support may consist of a silicon wafer, or a substrate made of any material and having any shape, for 15 instance made of sapphire or glass. Like the first substrate 1, the support 4 may be provided, beforehand, with superficial layers, of any kind.

20 The support 4 can be applied onto the surface of the first substrate using any direct assembling method: molecular adhesion, thermo-compression, electrostatic bonding, etc. It may also comprise applying an adhesive layer onto the support 4 and/or the first substrate 1, such as glue. The application of the support 4 may also correspond to the deposition of a 25 material onto the surface of the first substrate 1, with the deposited layer forming the support 4.

30 In a further step c), an embrittlement heat treatment is then applied to the assembly to be fractured 5. Such heat treatment weakens the first substrate 1 at the embrittlement plane 2, and supplies sufficient energy for the fracture wave, once initiated, to propagate in a self-sustained way. Such heat treatment is typically ranging from 150°C to 600°C for 30 minutes to 8 hours, for instance, for 4 hours at 400°C.

35 In a first alternative embodiment, the heat treatment is sufficient, in itself, to initiate the fracture wave. Upon completion of the heat treatment, the useful layer 3 is

totally removed from the first substrate 1, as shown in Figure 4d.

In a second alternative embodiment, shown in Figure 4c', the method comprises a local addition of energy, prior to, or during the embrittlement heat treatment, to initiate the fracture wave. Such energy may have a mechanical, thermal, or any other origin. It may originate for a local heating by a laser, for instance, or ultrasonic energy input.

Whatever the alternative embodiment, once initiated, the fracture wave propagates in a self-sustained way so as to detach and transfer the useful layer 2 onto the support 4, as shown in step d) in Figure 4.

According to the invention, the fracture wave which is created during one of the steps shown in Figures 4c and 4c' is initiated at a central area of the embrittlement plane 2. In these Figures, the initiation in the central area is symbolized by large arrows.

The fracture wave does not have to be initiated precisely at the geometric center of such plane 2. Thus, the central area of initiation may correspond to a circular surface substantially centered on the geometric center of the embrittlement plane. Such surface may correspond to 20%, 10% or 5% of the total surface of the embrittlement plane 2. As explained above, when the fracture is initiated at one point of this area, it is far enough from the edges of the assembly to be fractured 5 to delay the moment when the fracture wave interacts with the reflected acoustic wave.

Several approaches are possible to cause the initiation of the fracture in such central area. An incipient fracture can thus be placed in this area or close thereto, in a step prior to the step of heat treatment. During this step, the incipient fracture is an advantageous place for initiating such fracture.

Such incipient fracture can thus be formed by introducing light species into the first substrate 1, at the central area of the embrittlement plane 2. A volume, which defines the incipient fracture, is thus formed, and has light species in excess relative to the average concentration of the embrittlement plane 2. Such light species in excess can thus be introduced prior to, during, or after the step of forming the embrittlement plane 2, and in any case, prior to the step of assembling. The main dimensions of the incipient fracture can range from 10nm to a few millimeters. The species in excess can be introduced into the first substrate 1, by means of a local implantation, with or without a previous masking of such substrate 1. For instance, a local implantation of hydrogen on a surface, 1mm in diameter, in a dose (in addition to the one forming the embrittlement plane) of $1 \times 10^{16} \text{at/cm}^2$ makes it possible to initiate the fracture during the step of embrittlement heat treatment, specifically at such over-implanted area forming the incipient fracture.

The incipient fracture can also be formed at the assembling interface between the first substrate 1 and the support 4, in line with the central area of the embrittlement plane 2. It may consist of a cavity, for instance made by etching, at the surface of the first substrate 1 or the support 4, or of a body having reduced dimensions positioned at such interface. The presence of such body or cavity results in local stress during the embrittlement heat treatment, which favours the initiation of the fracture wave in the central area, as disclosed, for instance in document US2010330779.

When the fracture wave is caused during the step of embrittlement heat treatment because of the presence of an incipient fracture, such heat treatment can be evenly applied to the assembly to be fractured 5.

As an alternative to the insertion of an incipient fracture, or in addition thereto, the initiation can be caused

by local energy input at the central area during or after the step of embrittlement heat treatment. The issue may be configuring the heat treatment equipment so that, during the treatment, the central area receives more heat energy than the peripheral area.

It can also be the local application of energy using a light beam (a laser, for instance) or a particle beam (ions, electrons).

The issue can also be the application of additional mechanical energy such as, for example, vibrations transmitted by an ultrasonic generator, for instance a piezoelectric generator, at the central area.

In the last two examples, local energy input can be carried out during the step of embrittlement heat treatment or during a possible additional step dedicated to such local energy input.

Whatever the embodiment selected to initiate the fracture at the central area of the embrittlement plane 2, the invention also comprises controlling the fracture wave propagation speed so that it has a sufficient speed, thus limiting the interactions with the acoustic vibrations emitted upon the initiation and/or propagation thereof.

As explained above, a sufficient speed makes it possible to limit such interactions within a peripheral area. And the higher the speed, the smaller the surface of the peripheral area. The periodical patterns of variation in thickness are thus limited to this peripheral area of the useful layer 3. Thus, when the first substrate is made of silicon, the fracture wave propagation can advantageously be controlled to have a speed above 2km/sec and preferably between 2 and 4.5km/sec, or more preferably equal or close to 4km/sec, for example from 3.8 to 4.2km/sec.

More generally, and according to one preferred embodiment of the invention, the fracture wave propagation speed will be controlled so that it is higher than or equal to one third of the acoustic wave speed (i.e $V_g/3$), so that the peripheral area, wherein the periodical patterns are limited, is smaller than $R/2$.

Depending on the method selected for initiating the fracture (whether thermal and/or mechanical), the operational parameters of such method can be so selected as to control the fracture wave propagation speed. For this purpose, use can be made of the device for measuring the fracture wave speed disclosed in document WO2013140065.

Thus, when the fracture initiation is obtained, as regards temperature, for instance when the embrittlement heat treatment causes such initiation by itself, reference can be made to the document « fracture dynamics in implanted silicon » by D. Massy et Al, Applied Physics Letters 107 (2015), to select the temperature making it possible to obtain the targeted fracture wave speed. Particularly, a temperature above 400°C or 500°C can be selected. The document discloses a method making it possible to link the fracture wave propagation speed to the wave embrittlement and/or initiation operational parameters. It specifically mentions that, in the case of a first silicon substrate, the fracture wave propagation speed can be controlled between approximately 1km/sec and 4km/sec when the temperature, upon the initiation of the fracture, varies from about 300°C to 700°C .

In the second alternative embodiment which comprises a local energy input to initiate the fracture wave, the maturing rate of the embrittlement plane, as obtained upon completion of the embrittlement heat treatment, can vary. The maturing rate corresponds to the surface covered by micro-cracks formed in the embrittlement plane, upon applying local energy, causing the initiation of the fracture. As a matter of fact, the fracture wave propagation speed depends on the maturing

rate: the higher the parameter, the higher the fracture wave propagation speed.

5 Maturing rates can be measured by measuring the surface
covered by the micro-cracks, for instance, using an infrared
microscope to calibrate the embrittlement heat treatment
making it possible to reach a target fracture speed. Such heat
treatment can also be so adjusted that the embrittlement area
has a maturing rate at least equal to a target maturing rate,
10 which makes it possible to reach or exceed a targeted fracture
speed.

15 Figure 5a shows a view of the haze emitted by a useful
layer obtained by a method according to the invention.

20 The useful layer 3 of Figure 5a results from a method
comprising a step of forming an incipient fracture by
implanting an amount of 1.10^{16} at/cm² of hydrogen at the
geometric center of a first substrate consisting of a silicon
board. After assembling with a support also made of a silicon
board, the fracture was initiated at the incipient fracture,
during an embrittlement heat treatment at 350°C for 30 hours.
The fracture wave propagated at a speed of the order of
2.8km/sec.

25 It can be noted that the useful layer shown in Figure
5a has periodical patterns of variation in the thickness which
are limited to a peripheral annular area, the inner radius of
circle of which is larger than 80% of the radius of the useful
30 layer. The central surface of the useful layer is free of
periodical patterns of variation in thickness.

35 Figure 5b shows a view of a useful layer obtained by a
simulation of a method according to the invention, when the
fracture wave is propagated at 4km/sec.

This view of the useful layer 3 shows that a very narrow annular area comprising the periodical patterns of variation in thickness is provided on the periphery.

5 This last figure is a perfect illustration of the advantage which can be taken from the present invention to form a useful layer with enhanced evenness properties.

CLAIMS

1. A method for transferring a useful layer (3) onto a support (4) comprising the following steps:

- forming an embrittlement plane (2) by implanting light species into a first substrate (1), so as to form a useful layer (3) between such plane (2) and one surface of the first substrate (1);
- applying the support (4) onto the surface of the first substrate (1) so as to form an assembly to be fractured (5);
- applying a heat treatment for embrittling the assembly to be fractured (5);
- initiating and propagating a fracture wave into the first substrate (1) along the embrittlement plane (2);

with the method being characterized in that:

- the fracture wave is initiated in a central area of the embrittlement plane (2); and
- the propagation speed of such wave is controlled so that the velocity thereof is sufficient;

so that the interactions of the fracture wave with acoustic vibrations emitted upon the initiation and/or propagation thereof are limited to a peripheral area of the useful layer (3).

2. A method according to claim 1, wherein the propagation speed of the fracture wave is controlled so as to have a velocity higher than one third of the speed of the acoustic wave.

3. A method according to one of the preceding claims, wherein the first substrate (1) is made of silicon, and wherein the propagation of the fracture wave is controlled so as to have a velocity above 2km/sec.

4. A method according to the preceding claim, wherein the propagation of the fracture wave is controlled so as to have a velocity ranging from 2km/sec to 4.5km/sec.

5. A method according to claim 3, wherein the propagation of the fracture wave is controlled so as to have a velocity ranging from 3.8km/sec to 4.2km/sec.

5 6. A method according to one of the preceding claims, wherein the fracture wave is initiated by applying the embrittlement heat treatment and wherein the propagation speed is controlled by selecting the temperature of such heat treatment upon the initiation.

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7. A method according to the preceding claim, wherein the temperature of the embrittlement heat treatment is above 400°C, or 500°C.

15 8. A method according to one of the preceding claims, wherein the initiation of the fracture wave is caused by an incipient fracture positioned in the central area of the embrittlement plane (2), or in the vicinity of such central area.

20 9. A method according to the preceding claim, wherein the incipient fracture consists of a volume containing light species in excess as compared to the average concentration in the embrittlement plane (2).

25 10. A method according to claim 8, wherein the incipient fracture consists of a cavity or a body positioned at the interface between the first substrate (1) and the support (5) in line with the central area of the embrittlement plane (2).

30 11. A method according to one of claims 1 to 7, wherein the fracture wave is initiated by energy input at the central area of the embrittlement plane (2).

35 12. A method according to the preceding claim, wherein the propagation speed is controlled by calibrating the embrittlement heat treatment so that the embrittlement plane has a maturing rate at least equal to a target maturing rate.

13. A method according to one of the preceding claims, wherein the first substrate (1) consists of a disk-shaped board, and wherein the central area comprises the geometric center of the board.

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14. A method according to preceding claims, wherein the peripheral area consists of an annular area, the inner radius of circle of which is greater than $2/3$, and preferably greater than 80%, of the radius of the first substrate (1).

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15. A method according to the preceding claim, wherein the peripheral area is totally encompassed in one exclusion area of the useful layer (3).