

A METHOD AND APPARATUS FOR BONDING TOGETHER TWO WAFERS BY MOLECULAR ADHESION

Background of the invention

5 The present invention relates to the field of producing multilayer semiconductor structures (also known as composite structures or multilayer semiconductor wafers) produced by the transfer of at least one layer onto a final substrate. Said layer transfer is obtained
10 by bonding a first wafer (or initial substrate) onto a second wafer (or final substrate), for example by molecular adhesion, the first wafer generally being thinned after bonding. The transferred layer may also comprise all or a portion of a component or a plurality
15 of microcomponents.

More precisely, the present invention relates to the problem of bonding defects that may arise in a localized manner at the bonding interface between two wafers bonded by molecular adhesion.

20 Wafer bonding by molecular adhesion is a technique that is well known per se. It should be recalled that the principle of wafer bonding by molecular adhesion is based on bringing two surfaces into direct contact, i.e. without using a specific bonding material (adhesive, wax, solder, etc). Such an operation requires the surfaces
25 that are to be bonded to be sufficiently smooth, and free of particles or of contamination, and for them to be sufficiently close together to allow contact to be initiated, typically at a distance of less than a few
30 nanometers. The attractive forces between the two surfaces are then large enough to cause bonding by molecular adhesion or "direct bonding" (bonding induced by the various electronic interaction attractive forces (Van der Waals forces) between atoms or molecules of the
35 two surfaces to be bonded together).

Figures 1A to 1D show an example of the production of a multilayer structure comprising wafer bonding by

molecular adhesion of a first wafer 102 onto a second wafer 106 constituting a support wafer.

The first wafer 102 includes a series of microcomponents 104 on the bonding face 102a (Figure 1A).

5 The microcomponents 104 are formed by photolithography, employing a mask to define the zones for the formation of patterns corresponding to the microcomponents 104 to be produced.

10 The term "microcomponents" as used in this document means devices or any other patterns resulting from technical steps carried out on or in the layers and that need to be positioned accurately. Thus, they may be active or passive components, simple contact points, interconnections, etc.

15 Furthermore, the support wafer 106 is covered by a thermal or deposited oxide layer 108 formed by oxidation of the support wafer, for example, in order to facilitate bonding by molecular adhesion with the first wafer 102 (Figure 1A).

20 Further, a treatment is generally carried out to prepare the bonding surface 102a of the first wafer 102 and the bonding surface 106a of the second wafer 106, said treatment varying as a function of the bonding energy to be obtained (chemical-mechanical polishing, 25 cleaning, scrubbing, hydrophobic/hydrophilic treatment, etc).

Once the wafers have been prepared, the support wafer 106 is positioned in a bonding machine 115. More precisely, the support wafer 106 is positioned on the 30 substrate carrier 110 of the bonding machine 115 with a view to assembling it with the first wafer 102 by direct bonding. The substrate carrier 110 holds the second wafer 106 in position by means of an electrostatic system or by suction, for example.

35 The first wafer 102 is then placed on the second wafer 106 in order to come into intimate contact therewith (Figure 1B). Bonding by molecular adhesion is

then initiated by applying a contact force (mechanical pressure) to the first wafer 102 (Figure 1C).

Application of this contact force enables initiating propagation of a bonding wave 122 from that initiation point (Figure 1D). The bonding wave 122 is initiated by
5 means of an application tool 114 (for example a Teflon[®] stylus) with which the bonding machine 115 is provided.

The term "bonding wave" in this document is used for the binding or molecular adhesion front that is
10 propagated from the initiation point and that corresponds to the diffusion of attractive forces (Van der Waals forces) from the contact point over the entire area of intimate contact between the two wafers (bonding interface).

15 Propagation of the bonding wave 122 over the entire bonding surfaces of the wafers 102 and 106 then allows wafer bonding by molecular adhesion of the two wafers, in order to obtain a multilayer structure 112.

Once bonding has been carried out, it can be
20 reinforced by carrying out a thermal anneal. The first wafer 102 may then be thinned in order to form a transferred layer on the support wafer 106.

However, the Applicant has observed the presence of localized bonding defects 118 at the bonding interface
25 between the two wafers, and more precisely in a region 120 located remote from the bonding initiation point 116 (Figure 1E). Those defects correspond to zones in which the two wafers 102 and 106 have a very weak bonding force or even a complete absence of bonding.

30 The manufacturer does not want such bonding defects, since they reduce the quality of the bond between the wafers. More generally, those defects are evidence of a non-optimized fabrication process, which reduces the attraction of the multilayer structures produced.

35 Thus, there is currently a need to produce multilayer structures by wafer bonding by molecular adhesion that do not exhibit such bonding defects.

Object and summary of the invention

To this end, the present invention proposes a method of bonding a first wafer onto a second wafer by molecular
5 adhesion, the method comprising applying a point of
initiation of a bonding wave between said first and
second wafers, the method being characterized in that it
further comprises projecting a gas stream between the
first wafer and the second wafer towards the point of
10 initiation of the bonding wave while the bonding wave is
propagating between the wafers.

The invention acts mechanically to slow down the
propagation of the bonding wave at the interface between
the two wafers. Slowing down the bonding wave serves
15 advantageously to reduce or to prevent the appearance of
unwanted bonding defects at the bonding interface between
the first and second wafers.

The invention can also serve advantageously to limit
heterogeneous deformations being generated in the wafers
20 while they are being bonded by direct bonding.

In a preferred embodiment, the gas stream is
projected throughout the duration of propagation of the
bonding wave between the wafers. It is then possible to
optimize the effect of the above-described mechanical
25 opposition.

In accordance with another aspect of the invention,
the projected gas stream may be a stream of dry gas with
water at a concentration of 10000 ppm or less in order to
cause desorption of water over at least one of the
30 bonding surfaces for the two wafers.

In a particular embodiment, the projected gas stream
has water at a concentration of less than 1000 ppm [parts
per million].

A gas stream that is sufficiently dry (for example
35 having water at a concentration of less than 10000 ppm,
or even less than 1000 ppm) is thus projected between the
two wafers, thereby making it possible to trigger the

desorption of water bound in the form of condensation on the bonding surfaces of the first wafer and/or the second wafer. Projecting a dry gas stream is also advantageous in that it can reduce the quantity of saturated water
5 contained in the ambient air between the two wafers, thereby reducing the risk of water being adsorbed on the bonding surfaces of the two wafers in the form of condensation.

Further, the temperature of the gas stream may be in
10 the range from the ambient temperature of the first and second wafers to 200°C.

More precisely, the temperature of the gas stream projected between the two wafers may be of the order of ambient temperature, i.e. the temperature of the working
15 atmosphere, in order to prevent saturated water contained in the wafer surface environment from condensing and to prevent the wafers from deforming due to them expanding under the effect of temperature. Alternatively, the temperature of the projected gas stream may be above or
20 below ambient temperature and up to 200°C, for example, in order to maximize the desorption effect.

Heating the gas stream projected between the two wafers is advantageous in that it means that its ability to desorb from the bonding surfaces of the two wafers can
25 be augmented. A gas stream at such a temperature more easily triggers desorption of the water molecules close to the surfaces.

In a particular embodiment of the invention, the gas stream is selected from at least a stream of helium,
30 argon, neon, nitrogen, carbon dioxide (CO₂), and a stream of air. The gas stream may in particular correspond to one of said gaseous elements or to any combination of some of said elements.

Further, the width of the gas stream may correspond
35 to the diameter of the two wafers.

Such a stream width means that the formation of bonding defects can be limited or prevented over the entirety of the bonding interface between the two wafers.

The gas stream may also be a laminar flow.

5 The invention also envisages an apparatus for bonding by molecular adhesion a first wafer onto a second wafer, including means for applying a point of initiation of a bonding wave between the first and second wafers, the apparatus being characterized in that it further
10 includes projection means configured to project a gas stream between the first and second wafer towards the point of initiation of the bonding wave while the bonding wave is propagating between the wafers.

The advantages and comments set out above with
15 reference to the various implementations of the bonding method of the invention are analogously applicable to the various embodiments of the bonding apparatus of the invention.

In accordance with one aspect of the invention, the
20 projection means of the bonding apparatus may be configured to project a gas stream that is dry, having water at a concentration of less than 10000 ppm, in order to cause desorption of water over at least one of the bonding surfaces of the two wafers.

25 In a particular embodiment, said projection means are configured such that the gas stream has water at a concentration of less than 1000 ppm.

Further, the projection means may be configured in order to project the gas stream at a temperature in the
30 range from the ambient temperature of the first and second wafers to 200°C.

Furthermore, the gas stream projected between the two wafers may be selected from at least a stream of helium, argon, neon, nitrogen, carbon dioxide (CO₂), and
35 a stream of air. In particular, the gas stream may correspond to one of said gaseous elements or to any combination of several of said elements.

Furthermore, the projection means may be configured such that the width of the gas stream corresponds to the diameter of the two wafers. In addition, the gas stream may be a laminar flow.

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Brief description of the drawings

Other characteristic and advantages of the present invention become apparent from the description below, made with reference to the accompanying drawings that
10 illustrate an example of an embodiment and that is not limiting in any way. In the figures:

- Figures 1A to 1D diagrammatically show an example of a known prior art direct wafer bonding method;
- Figure 1E diagrammatically shows the bonding
15 defects appearing during the bonding method illustrated in Figures 1A to 1D;
- Figure 1F diagrammatically illustrates the mechanism whereby the bonding defects represented in Figure 1E are formed;
- 20 • Figures 2A to 2D diagrammatically show a direct wafer bonding method in accordance with a first implementation of the invention; and
- Figures 3A and 3B diagrammatically show a direct wafer bonding method in accordance with a second
25 implementation of the invention.

Detailed description of an implementation

In general, the present invention relates to a method of bonding two wafers by molecular adhesion, said
30 method being used to prevent the appearance of unwanted bonding defects at the bonding interface.

As indicated above, the Applicant has observed bonding defects appearing in a localized manner at the bonding interface of a multilayer structure formed by
35 direct wafer bonding of a first wafer to a second wafer.

The wafers composing a multilayer structure are generally in the form of wafers that have a generally

circular outline and that may have various diameters, especially diameters of 100 mm [millimeter], 200 mm or 300 mm. However, the wafers may have any shape, such as a rectangular shape, for example.

5 An in-depth study of the bonding defects 118 illustrated in Figure 1E has been used to elucidate the mechanism whereby said defects are formed and to devise a method to prevent their formation.

10 The mechanism at the origin of the defects 118 is described below with reference to Figures 1A to 1F.

 As explained above, the initiation of wafer bonding by molecular adhesion is carried out by applying a contact force at an initiation point 116 located close to the side of the first wafer 102 (Figure 1C). This
15 contact force can be applied to initiate propagation of a bonding wave 122 starting from the initiation point 116 (Figure 1D).

 As the bonding wave 122 propagates, it pushes out the ambient air present between the two wafers together
20 with excess water molecules adsorbed on the surface.

 It appears that surface irregularities 124 (surface topology or nano-topology, fine particles, micro-scratches, etc) may cause condensation at said irregularities of saturated water that is contained in
25 the air being evacuated by the bonding wave 122 (Figure 1F).

 Hence, when the bonding wave 122 has propagated up to the point remote from the initiation point 116, an excess of water molecules may be found to be trapped in
30 the form of condensation at the surface irregularities 124 such as, for example, in a region denoted 120 of the bonding surfaces 102a and 106a of the two wafers (Figure 1F).

 The water that condenses at the surface
35 irregularities 124 of the region 120 then prevents normal bonding of the two wafers by molecular adhesion. Bonding defects 118 then appear at the bonding interface, for

example at the surface irregularities 124. In practice, said bonding defects take the form of air bubbles (such as edge voids) that develop when a heat treatment is applied to reinforce the bonding energy.

5 Such defects are unwanted since they deteriorate the quality of the bond of the wafer 102 to the wafer 106. These bonding defects 118 may in particular cause accidental snap-off of portions of the wafer 102 in the vicinity of the defects when the wafer 102 undergoes a
10 thinning step (for example by grinding and/or chemical attack).

To this end, the present invention proposes carrying out a method of wafer bonding by molecular adhesion involving projecting a gas stream between the two wafers
15 that are to be assembled together, in order to prevent the appearance of bonding defects as described above, especially at the side of the wafer. Slowing down the bonding wave means that evacuation of excess water close to the surfaces can be facilitated.

20 A particular embodiment of the bonding method of the invention is described below with reference to Figures 2A to 2D.

Bonding by molecular adhesion of a first wafer 202 onto a second wafer 206 constituting a support wafer is
25 carried out (Figure 2A). These wafers are respectively identical to wafers 102 and 106 considered in Figure 1A.

More precisely, the first wafer 202 in this example comprises microcomponents 204 at its bonding surface 202a. Further, oxidation is carried out on the second
30 wafer 206 to form a layer of thermal oxide 208 over its entire surface. It should be noted that it is possible to deposit a layer of oxide on only the bonding surface 206a of the second wafer 206. Alternatively, a layer of oxide may be formed over the bonding surface 202a of the
35 first wafer 202.

It should also be pointed out that the first and second wafers 202 and 206 have the same diameter in this

instance. However, they could have different diameters or they could be non-circular in shape.

Furthermore, the wafers 202 and 206 may have surface irregularities at the side of the wafer analogous to the
5 surface irregularities 124 illustrated in Figure 1F.

In this implementation of the invention, first of all, the support wafer 206 is placed in a bonding machine 215, and more precisely on a substrate carrier 210 provided on the bonding machine 215. The machine 215
10 also comprises a nozzle 226 (described below) and an application tool 214 identical to the application tool 114 described above.

Once the support wafer 206 has been positioned on the substrate carrier 210, the first wafer 202 is placed
15 in intimate contact with the support wafer (Figure 2B). A bonding wave 222 is then initiated between the wafers 202 and 206 in order to bond them by molecular adhesion.

In this example, the wave 222 is initiated by using the application tool 214 to apply contact force at the
20 initiation point 216 located in the vicinity of the side of the wafer 202 (Figure 2C). Application of this contact force means that propagation of a bonding wave 222 from the initiation point 216 (Figure 2D) can be triggered.

25 However, it should be noted that other operating modes can be used to initiate propagation of a bonding wave. Under certain conditions in particular, it is possible to trigger initiation of said wave propagation without applying mechanical pressure on the upper wafer
30 202.

Once the bonding wave has been initiated, a gas stream 228 is projected between the two wafers by means of a nozzle 226 included in the bonding machine 215 (Figure 2D). The gas stream 228 is then projected while
35 the bonding wave propagates between the two wafers 202 and 206.

Preferably, projection of the gas stream is triggered simultaneously with initiation of the bonding wave. If necessary, projection of the gas stream may be triggered a few moments before initiating the bonding
5 wave.

Still preferably, projection of the gas stream is maintained throughout the period for propagation of the bonding wave between the wafers. In this manner, the mechanical braking effect described in more detail below
10 is optimized.

It may be a stream of air or a stream of gas (or a gas mixture), for example a stream of rare gas (helium, argon and/or neon, for example), a stream of nitrogen and/or a stream of carbon dioxide.

By way of example, said gas stream is in the form of a very narrow jet (also known as a gas knife or air knife) capable of penetrating between the two wafers in intimate contact. The flow cross-section of the nozzle
15 226 is preferably of the order of magnitude of the separation of the wafers, i.e. of the order of 10 μm
20 [micrometer], for example, and in any event less than the thickness of the wafers. The wafers are approximately 500 μm thick, for example.

Further, in the example described here, the gas
25 stream 228 is sufficiently wide to be capable of flushing the entirety of the bonding surfaces 202a and 206a of the wafers 202 and 206 respectively. However, as indicated in more detail below, other gas stream configurations may be envisaged.

Further, blocks 230A, 230B, and 230C (collectively denoted 230) attached to the substrate carrier 210 are positioned in abutment against the peripheral side of the wafers 202 and 206. These blocks are configured in order to prevent the position of the first wafer 202 from being
30 offset from that of the support wafer 206 under the action of the gas stream 228.
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However, it should be understood that other forms and dispositions of the blocks 230 are possible. As an example, the number of blocks may be reduced to two if necessary (or even to one if the shape of the block employed allows it).

Furthermore, the gas stream 228 is projected such that it is generally directed in the direction of the initiation point 216, preferably perpendicular to the bonding wave.

The gas stream 228 is preferably laminar so that the force applied to the surface of the wafers 202 and 206 is effective.

As can be seen in Figure 2D, the nozzle 226 envisaged here has an inwardly curved profile such that the side thereof remains at a constant distance from the periphery of the wafers 202 and 206. This configuration for the nozzle is advantageous in that it can be used to project the gas stream 228 in a direction generally perpendicular to the propagation of the bonding wave 222.

In the example considered here, the initiation point 216 is positioned close to the peripheral side of the first wafer 202. As indicated above, this configuration is preferred since it means that the bonding wave can propagate over a large distance and, in the portion remote from the initiation point 216, it can form a zone that is almost without heterogeneous deformation. The initiation point 216 is then preferably positioned opposite from the nozzle 226.

However, it should be noted that it is possible to apply the contact force at any initiation point on the exposed surface of the first wafer 202.

The gas stream 228 is directed so as to mechanically brake the propagation of the bonding wave 222 between the wafers 202 and 206. By orienting the nozzle 226 towards the initiation point 216, the gas stream 228 in fact causes the application of a force that opposes the propagation of the bonding wave 222. The embodiment

described here can effectively slow down propagation of the bonding wave 222 in a uniform manner over the entire bonding surface of the wafers 202 and 206. This slowdown is explained by the fact that the gas stream 228 applies
5 mechanical pressure between the bonding surfaces 202a and 206a of wafers 202 and 206, said pressure thereby slowing down the approach of the wafers during the passage of the bonding wave and allowing excess water to be evacuated.

The Applicant has shown that slowing down the
10 propagation of the bonding wave means that the appearance of the bonding defects described above can be significantly reduced.

Slowing down of the bonding wave 222 also means that ambient air located between the two wafers can be
15 evacuated more effectively. In this manner, the saturated water contained in the air between the two wafers is less susceptible to condensing at the surface irregularities 224.

Typically and when the invention is not applied, the
20 bonding wave 222 takes about 8 to 10 seconds to propagate over the entirety of the bonding surfaces 202a and 206a when said wafers have a diameter of 300 mm and when bonding oxide to oxide, or when one of the two wafers has been activated by plasma treatment. In contrast, when
25 the invention is employed, the bonding wave is slower: in the implementation considered here, the bonding wave takes more than 10 seconds to propagate over the entirety of the bonding surfaces. Nevertheless, the bonding wave propagation time varies as a function of the surface
30 treatments carried out on the two wafers to be assembled. In fact, the more hydrophilic are the bonding surfaces, the higher will be the propagation rate of the bonding wave 222.

Furthermore, the gas stream 228 is preferably dry.
35 As an example, it has water at a concentration of less than 10000 ppm, or even less than 1000 ppm.

The gas stream 228 projected between the two wafers may be heated in order to increase its desorbing power. The higher is the temperature of the gas stream 228, the more susceptible it is to cause evaporation of water trapped in the form of condensation at the surface irregularities 224. The gas stream 228 may be heated to a temperature that is preferably in the range from the ambient temperature of the environment of the two wafers to 200°C.

Furthermore, as indicated above, bonding two wafers by molecular adhesion generates substantial mechanical stresses that are the source of heterogeneous deformations in the wafers. For example, if the wafer 202 is thinned after bonding and a second series of microcomponents is fabricated on the exposed face of the wafer 202 using a photolithography mask similar to that used to fabricate the first series of microcomponents 204, non-uniform overlays might appear between the two series of microcomponents due to the heterogeneous deformations brought about by the wafer bonding by molecular adhesion.

The term "similar photolithography masks" means masks that are designed to be used in combination during a fabrication process.

The slowing down of the propagation of the bonding wave that results from projecting a gas stream 228 during said propagation advantageously serves to reduce the heterogeneous deformations that are generated during direct wafer bonding of the two wafers, thereby reducing the risks of overlays between the two faces of the first wafer 202. In addition, in order to reduce as many of said heterogeneous deformations as possible, the temperature of the gas stream 228 is preferably set at the ambient temperature of the wafers or at a temperature of the same order.

In accordance with a second implementation of the invention shown in Figures 3A, 3B and 3C, a first wafer

302 is bonded to a second wafer 306 by molecular
adhesion. This implementation differs from the first
implementation described above in that it is carried out
using a bonding machine 315 that is substantially
5 different from the bonding machine 215. More precisely,
the bonding machine 315 comprises a substrate carrier 310
and an application tool 314 for applying a bonding
initiation point to the first wafer 302. However, the
bonding machine 315 differs from the bonding machine 215
10 in that it is also provided with a plurality of nozzles
332 all directed towards the bonding initiation point
denoted 316.

The bonding machine 315 may also comprise a
servocontrol to program the nozzles 332 and control the
15 direction of projection of the gas streams 328 delivered
by each of the nozzles 332. As an example, the bonding
machine is configured to detect, by means of a position
sensor, the position of the initiation point 316 applied
by the application tool 314. Once the position of the
20 initiation point 316 has been determined, the bonding
machine 315 orients the nozzles 332 so that each gas
stream 328 is directed towards that initiation point or,
as is preferable, in a direction perpendicular to the
propagation of the wave.

25 In a manner analogous to the implementation of
Figures 2A to 2D, the bonding machine of said second
implementation is configured to project the gas stream
between the wafers during propagation of the bonding
wave. This second implementation can thus effectively
30 and uniformly slow down propagation of the bonding wave
at the interface between the two wafers and thus
significantly reduce the appearance of bonding defects.

CLAIMS

1. A method of bonding a first wafer (202) onto a second wafer (206) by molecular adhesion, the method comprising applying a point (216) of initiation of a bonding wave
5 (222) between said first and second wafers, the method being characterized in that it further comprises projecting a gas stream (228) between the first wafer and the second wafer towards the point of initiation of the bonding wave while the bonding wave is propagating
10 between said wafers.

2. A method according to claim 1, wherein the projected gas stream is a stream of dry gas having water at a concentration of less than 10000 ppm, in order to cause
15 desorption of water over at least one of the bonding surfaces (202a, 206a) of the two wafers.

3. A method according to claim 1 or claim 2, wherein the temperature of said gas stream is in the range from the
20 ambient temperature of said first and second wafers to 200°C.

4. A method according to any one of claims 1 to 3, wherein said gas stream is selected from at least a
25 stream of argon, a stream of neon, a stream of helium, a stream of nitrogen, a stream of carbon dioxide, and a stream of air.

5. A method according to any one of claims 1 to 4,
30 wherein the width of the gas stream corresponds to the diameter of the two wafers.

6. Apparatus (215) for bonding by molecular adhesion a first wafer (202) onto a second wafer (206), the
35 apparatus including means (214) for applying a point of initiation (216) of a bonding wave (222) between the first and second wafers, said apparatus being

characterized in that it further includes projection means (226) configured to project a gas stream (228) between the first and second wafers towards the point of initiation of the bonding wave while the bonding wave is
5 propagating between said wafers.

7. An apparatus according to claim 6, wherein the projection means are configured to project a stream of dry gas having water at a concentration of less than
10 10000 ppm, in order to cause desorption of water over at least one of the bonding surfaces (202a, 206a) of the two wafers.

8. An apparatus according to claim 6 or claim 7, wherein
15 the projection means are configured to project the gas stream at a temperature in the range from the ambient temperature of said first and second wafers to 200°C.

9. An apparatus according to any one of claims 6 to 8,
20 wherein said gas stream is selected from at least a stream of argon, a stream of neon, a stream of helium, a stream of nitrogen, a stream of carbon dioxide, and a stream of air.

25 10. An apparatus according to any one of claims 6 to 9, wherein the projection means are configured such that the width of the gas stream corresponds to the diameter of the two wafers.