

METHOD FOR MOLECULAR ADHESION BONDING WITH COMPENSATION FOR RADIAL MISALIGNMENT

Technical Field and Prior Art

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The present invention concerns the field of multilayer semiconductor wafers or structures produced according to the technology of three-dimensional integration (3D integration) which involves the transfer onto a first wafer, referred to as the final substrate, of at least
10 one layer formed from a second wafer, this layer corresponding to the portion of the second wafer in which elements have been formed, for example a plurality of microcomponents, other corresponding elements also being formed in the first wafer.

Particularly owing to the very small size and the large number of
15 microcomponents present on a given layer, each transferred layer, that is to say each wafer comprising the layer, must be positioned on the final substrate (the first wafer on its own or already comprising other transferred layers) with great precision in order to comply with very strict alignment with the underlying layer. It may furthermore be necessary to
20 carry out treatments on the layer after its transfer, for example in order to form other microcomponents, in order to uncover microcomponents on the surface, in order to produce interconnects, etc., these treatment operations also having to be carried out with very great precision in relation to the components present in the layer.

25 The transfer of a layer onto the final substrate involves molecular adhesion bonding between a first wafer and a second wafer, of the type described above, the second wafer generally being subsequently thinned. During the bonding, the wafers are mechanically aligned. Three types of alignment defects may be observed between the two wafers, namely
30 alignment defects of the "offset" or "shift" type, of the rotation type and of the radial type (also known by the name "run-out", magnification error or deformation error).

When a sequence of lithography steps is carried out on a single wafer, these types of defects are generally corrected by using a

compensation algorithm in a lithography machine in order to preserve perfect alignment between each step.

During alignment between two wafers with a view to bonding, the alignment defects of the shift and rotation types can be compensated for mechanically by modifying the relative position of the wafers with respect to one another in the bonding machine. However, the alignment defects of the radial type cannot be compensated for by such repositioning of the wafers.

The radial misalignment occurs when two wafers to be aligned have different radial expansions; the radial expansions may be due to the fact that each wafer has undergone a different process of fabricating microcomponents and/or the fact that the processes applied to one or other of the wafers can lead to them being strained and make their dimensions vary on the microscopic scale, as in the case for example of layer deposition or oxidation which induces tensile strains for the wafer.

Figure 1A illustrates the alignment between a first wafer 10 and a second wafer 20 with a view to bonding them by molecular adhesion. A first series of microcomponents 11 has been formed beforehand on the bonding face of the first wafer 10, while a second series of microcomponents 21 has been formed beforehand on the upper face of the second wafer 20, intended to be bonded to the first wafer. The microcomponents 11 are intended to be aligned with the microcomponents 21 after bonding of the wafers.

In the example described here, however, the first and second wafers have different radial expansions, thus creating a radial misalignment between these wafers which, after bonding, results in offsets between the majority of the microcomponents such as the offsets Δ_{11} , Δ_{22} , Δ_{33} , Δ_{55} , Δ_{66} or Δ_{77} indicated in Figure 1B (respectively corresponding to the offsets observed between the pairs of microcomponents $11_1/12_1$, $11_2/12_2$, $11_3/12_3$, $11_5/12_5$, $11_6/12_6$ and $11_7/12_7$).

The radial expansions responsible for the radial misalignment between two wafers are generally homogeneous over the wafers, thus creating a radial misalignment which evolves (i.e. increases) quasi-linearly between the centre and the periphery of the wafer.

The radial misalignment may be corrected in particular during the conventional steps of forming components by photolithography, by means of a correction algorithm and as a function of misalignment measurements carried out on a wafer.

5 However, the correction of the radial misalignment can be carried out only on one wafer on its own. Moreover, when the production of the microcomponents involves a step of bonding between two wafers as is the case when producing three-dimensional structures, it is no longer possible to carry out corrections relating to the radial misalignment.

10 Furthermore, when a layer of microcomponents is transferred onto a final substrate having a first layer of microcomponents, it is very important to be able to minimize the radial misalignment between these microcomponents of each of the layers when they are intended to be interconnected together. It is not in fact possible to compensate by
15 lithography for the misalignments existing between the microcomponents of the two layers in this case.

Summary of the Invention

20 It is an object of the invention to provide a solution which makes it possible to compensate for the initial radial alignment existing between two wafers intended to be bonded together.

To this end, the present invention provides a method for bonding a first wafer on a second wafer by molecular adhesion, the said wafers
25 having an initial radial misalignment between them, the method comprising at least a step of bringing the two wafers in contact so as to initiate the propagation of a bonding wave between the two wafers, characterized in that a predefined bonding curvature is imposed on at least one of the two wafers during the contacting step as a function of the
30 initial radial misalignment.

As explained below in detail, by monitoring the curvature of the wafers during their bonding, it is possible to induce an additional radial misalignment which will compensate for the radial misalignment initially existing.

According to one aspect of the invention, the second wafer is free to adapt to the predefined bonding curvature imposed on the first wafer during the propagation of the bonding wave.

5 According to another aspect of the invention, the wafers are circular wafers of silicon with a diameter of 300 mm, each comprising microcomponents.

According to one aspect of the invention, the method comprises the following steps before the bonding of the wafers:

- 10 - measurement of the initial radial misalignment between the two wafers to be compensated,
- measurement of the curvature of each wafer before bonding,
- determination of a compensation radial misalignment for the initial radial misalignment between the two wafers,
- calculation of a post-bonding curvature capable of generating
- 15 the said compensation radial misalignment between the two wafers,
- calculation of the predefined bonding curvature as a function of the calculated post-bonding curvature.

According to a particular aspect of the invention, the method comprises the following steps:

- 20 - holding the first wafer and the second wafer facing one another respectively using a first holding support and a second holding support, the said first support imposing the said predefined bonding curvature on the first wafer,
- bringing the said wafers in contact in order to initiate the
- 25 propagation of a bonding wave between the said wafers,
- releasing the second wafer from the second holding support before or while being brought in contact with the first wafer, so that the said second wafer adapts to the bonding curvature imposed on the first wafer during the propagation of the bonding wave.

30 According to one characteristic of the invention, the predefined bonding curvature is imposed on the first wafer by actuating a jack mounted on the first holding support.

According to another characteristic of the invention, the predefined bonding curvature is imposed on the first wafer by a

35 membrane interposed between the first wafer and the first holding

support, the said membrane having a curvature corresponding to the said predefined bonding curvature.

According to yet another characteristic of the invention, the predefined bonding curvature is imposed on the first wafer by the first holding support, the said first holding support having a curvature
5 corresponding to the said predefined bonding curvature.

According to a particular aspect of the invention, the wafers each comprise microcomponents on their respective bonding face, at least some of the microcomponents of one of the wafers being intended to be aligned with at least some of the microcomponents of the other wafer.
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The present invention also relates to an apparatus for bonding a first wafer on a second wafer by molecular adhesion, the said wafers having an initial radial misalignment between them, the apparatus comprising a first and second holding support for respectively holding the first wafer and the second wafer, in which apparatus the first holding support comprises means for imposing a predefined bonding curvature on the first wafer as a function of the initial radial misalignment, the apparatus controlling the second holding support in order to release the second wafer from the second support before or while being brought in contact with the first wafer, so that the said second wafer adapts to the bonding curvature imposed on the first wafer during the propagation of a bonding wave.
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According to one characteristic of the invention, the bonding apparatus comprises processing means for calculating the predefined bonding curvature as a function of the initial radial misalignment, or a radius of curvature corresponding to the said predefined bonding curvature as a function of the initial radial misalignment.
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According to one characteristic of the invention, the first holding support furthermore comprises a jack capable of imposing the predefined bonding curvature on the first wafer, the jack being driven according to a radius of curvature corresponding to the said predefined bonding curvature, the apparatus controlling the second holding support in order to release the second wafer from the second support after being brought in contact with the first wafer, so that the said second wafer adapts to the
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bonding curvature imposed on the first wafer during the propagation of a bonding wave.

5 According to another characteristic of the invention, the apparatus furthermore comprises a membrane interposed between the first wafer and the first holding support, the said membrane having a curvature corresponding to the said predefined bonding curvature.

According to yet another characteristic of the invention, the first holding support has a curvature corresponding to the said predefined bonding curvature.

10 According to one aspect of the invention, the first and second holding supports comprise means for holding the wafers by suction or by electrostatic force.

According to another aspect of the invention, the first and second holding supports are adapted to receive circular substrates with a diameter of 100 mm, 150 mm, 200 mm or 300 mm.

Brief Description of the Figures

20 - Figures 1A and 1B are schematic views showing the production of a three-dimensional structure according to the prior art,

- Figures 2 and 3 show wafers having deformations of the "bow" type,

- Figures 4A to 4C show the various curvatures obtained before, during and after the bonding of two wafers by molecular adhesion,

25 - Figures 5A to 5G are schematic views showing the production of a three-dimensional structure by using the molecular adhesion bonding method of the present invention,

- Figure 6 is a flow chart of the steps employed during the production of the three-dimensional structure illustrated in Figures 5A to 5G,

30 - Figure 7 is a graph showing the variation of a final radial misalignment as a function of the curvature imposed on two wafers during their bonding by molecular adhesion.

Detailed Description of Embodiments of the Invention

5 The present invention applies in general to the bonding by molecular adhesion between two wafers which have different radial expansions, leading to a radial misalignment between them after bonding.

The invention applies more particularly, but not exclusively, to the bonding by molecular adhesion between at least two wafers, each comprising components, in which at least some of the components of each of the wafers are intended to be aligned after bonding.

10 In order to compensate for the phenomenon of radial misalignment of the wafers after bonding, the present invention proposes to impose a bonding curvature, which has been defined beforehand as a function of the initial radial misalignment, on the wafers during their bonding.

15 More precisely, before bonding, each of the two wafers has its own curvature, which may be concave as in the case of the wafer 30 in Figure 2 or convex as in the case of the wafer 40 in Figure 3. This curvature determines the curvature deformation of the wafers, which is referred to by the term "bow" in semiconductor technology. As illustrated
20 in Figures 2 and 3, the bow Δz of a wafer corresponds to the distance (arrow), generally measured level with the centre of the wafer, between a reference plane P (typically perfectly flat), on which the wafer rests freely, and the wafer itself. On the scale of the wafer diameters conventionally used in the field of semiconductors, namely between a few tens of
25 millimetres and 300 millimetres, the bow is measured in micrometres whereas the curvature is generally measured in m^{-1} or km^{-1} , because the curvature of the wafers used in the field of semiconductors is very small and, consequently, the corresponding radius of curvature is very large.

30 Figures 4A to 4C show the variation of the curvatures before and after bonding of a first wafer 50 (top) on a support wafer 60 (base) respectively having an initial curvature K_1 and K_2 (Figure 4A). During the molecular adhesion bonding, a curvature K_b referred to as the bonding curvature is imposed on one of the two wafers 50 and 60 (Figure 4B), the other wafer being adapted to the curvature imposed on this first wafer
35 during the propagation of the bonding wave, as described in detail below.

The curvature K_B may be imposed by specific holding supports of a bonding machine, as described in detail below, the curvature K_B being for only one of the two wafers while the other wafer is free to deform at the moment when the propagation of the bonding wave is initiated, in order to adapt during this propagation to the curvature imposed on the other wafer.

Once the bonding has been carried out and the wafers have been released from their respective holding supports, the structure constituted by the combination of the bonded wafers 50 and 60 has a curvature K_F referred to as the post-bonding curvature.

The post-bonding curvature K_F may be calculated with the following formula:

$$K_F = (2(K_1 + K_2) + 12K_B) / 16 \quad (1)$$

This formula was determined on the basis of Formula (12) given in the document T. Turner et al., entitled "Mechanics of wafer bonding: Effect of clamping", Journal of Applied Physics, Vol. 95, N° 1, January 1, 2004.

On the basis of this formula, it can be seen that the influence of the bonding curvature K_B on the post-bonding curvature K_F predominates (by a factor of 6) over that of the initial curvatures K_1 and K_2 , respectively, of the wafers 50 and 60.

Furthermore, the radial misalignment D_R resulting between the two wafers after bonding may be determined by the following formula:

$$D_R = -2(\varepsilon R) \quad (2)$$

where R is the distance between the centre of the wafer at the measurement point of the radial misalignment and ε is the strain exerted on the surface of the first wafer 50 (top).

There is furthermore a relationship between the strain exerted on the surface of the first wafer and the post-bonding curvature K_F , which is given by the following formula:

$$\varepsilon = K_F (h/2) \quad (3)$$

where h is the thickness of the first wafer.

5 By introducing the elements of Formula (3) corresponding to the strain ε into Formula (2), the relationship between the radial misalignment D_R resulting after bonding and the post-bonding curvature K_F is established by the following formula:

$$10 \quad D_R = -K_F h R \quad (4)$$

It can be seen that the radial misalignment D_R is a function of the post-bonding curvature K_F .

15 Consequently, by knowing the initial radial misalignment D_{Ri} , a compensation radial misalignment D_{Rc} is determined such that: $D_{Rc} = -D_{Ri}$, which with Formula (4) gives: $D_{Rc} = K_F h R$

20 The initial radial alignment may be measured by carrying out bonding between two wafers of the same batch of wafers and measuring the misalignment of the two wafers in order to deduce the initial radial component therefrom. The two wafers have alignment marks, such as simple crosses (measurement methods by means of Vernier or Moiré structures) which make it possible to measure the misalignment in microns by infrared microscopy or confocal infrared microscopy, and to do so at a plurality of positions on the wafer which generally lie at its centre and periphery. The various misalignment components, and in particular the radial misalignment, can be extracted from these measurements. These measurements are generally carried out level with alignment marks arranged at the centre and periphery of the wafer, for example at 147 mm from the centre of a 300 mm wafer. At the periphery, the radial misalignment is maximal and may exceed one micron, as presented in Figure 7, which is measurable with the microscopic measurement techniques described above.

25 In this way the initial radial alignment is known for an entire batch of wafers, to which it is possible to apply the bonding method of the invention and compensate for the initial radial misalignment. The pair of
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wafers used for measuring the initial radial misalignment may be withdrawn from the batch or separated in order to re-bond the wafers with the bonding curvature predetermined according to the invention.

5 This initial radial misalignment could also be determined by precisely measuring the distance between two microcomponents (to within 0.33 ppm) on each of the two wafers taken separately, and by comparing these two differences.

10 On the basis of this last Formula (4), the target post-bonding curvature K_{Fc} allowing the compensation radial misalignment to be obtained is calculated according to the formula:

$$K_{Fc} = D_{Rc}/(h.R) \quad (5)$$

15 Formula (1) shows that the post-bonding curvature K_F is determined as a function of the initial curvatures K_1 and K_2 of the two wafers and the bonding curvature K_B . Since the curvatures K_1 and K_2 correspond to the intrinsic curvatures of the two wafers, only the curvature K_B represents the variable parameter making it possible to adjust the value of the post-bonding curvature K_F .

20 Thus, the target value of the post-bonding curvature K_{Fc} making it possible to obtain the compensation radial misalignment having been calculated on the basis of Formula (5) and the curvatures K_1 and K_2 having been measured beforehand, for example by means of optical measurement tools such as KLA-Tencor Flexus from KLA-Tencor Corp (or
25 by any measurement by a capacitive gauge, optical profilometry or mechanical profilometry which makes it possible to determine the bow), the bonding curvature K_B to be imposed during it to the wafers in order to obtain the target post-bonding curvature K_{Fc} is calculated such that:

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$$K_B = (8K_F - (K_1 + K_2))/6 \quad (6)$$

35 An exemplary production of a three-dimensional structure by transferring a layer of microcomponents which is formed on a first wafer 100 onto a second wafer 200, using a method of bonding with compensation for the radial misalignment according to an embodiment of

the invention, will now be described with reference to Figures 5A to 5G and 6. The wafers may in particular have diameters of 150 mm, 200 mm and 300 mm.

5 The production of the three-dimensional structure starts with the formation of a first series of microcomponents 110 on the surface of the first wafer 100 (Figure 5A, Step S1) and a second series of microcomponents 210 on the surface of the second wafer 200 (Figure 5B, Step S2). The microcomponents 110 and 210 may be entire components and/or only a part thereof. In the example described here, the first wafer
10 100 is a wafer with a diameter of 300 mm of the SOI type (Silicon on Insulator) comprising a layer of silicon 103 on a support 101 also made of silicon, a buried oxide layer 102, for example of SiO_2 , being arranged between the layer and the silicon support. The wafer 100 may also consist of another type of multilayer structure or a monolayer structure.

15 The second wafer 200 is a silicon wafer with a diameter of 300 mm.

The microcomponents 110 and 210 are formed by photolithography by means of a mask making it possible to define the regions for formation of patterns corresponding to the microcomponents
20 to be produced.

The microcomponents 110 and 210 are intended to interact with one another, for example in order to form finished components by joining microcomponents 110 and 210 in pairs, each constituting a part of the component to be produced, or in order to form interconnect circuits for
25 corresponding microcomponents 110 and 210. It is therefore important to be able to ensure good alignment between the microcomponents 110 and 210 after bonding of the wafers.

According to the invention, a bonding machine is used which, during the bonding, imposes a bonding curvature K_B on one of the wafers
30 while allowing the other wafer to adapt to the imposed curvature by propagation of the bonding wave between the two wafers. This operation makes it possible to obtain a target post-bonding curvature K_{Fc} which introduces between the two wafers the compensation radial misalignment D_{Rc} which will compensate for the initial radial misalignment D_{Ri} existing
35 between the two wafers and induced (differential radial expansions

between the wafers) during the various treatment steps carried out beforehand on each of the wafers before their bonding (lithography, layer deposition, heat treatments, etc.).

As illustrated in Figure 5C, the bonding operation is carried out with a bonding machine or apparatus 300 which comprises a first support plate 310 having a holding surface 311 intended to hold the first wafer 100 facing a second wafer 200, which is held on the holding surface 321 of a second support plate 320 of the machine 300. The support plates 310 and 320 are both equipped with holding means (not represented in Figure 5C) such as electrostatic or suction holding means. The first and second support plates 310 and 320 are each mobile along displacement directions d_{px} and d_{py} which make it possible, on the one hand, to position the wafers facing one another while compensating for the misalignment errors in rotation and translation and, on the other hand, to bring the holding surfaces 311 and 321, respectively, of the first and second support plates 310 and 320 towards or away from one another. To this end, each support plate is for example mounted on an actuator (not represented in Figure 5C) which is controlled by the bonding machine in order to adjust the distance between the two supports along the direction d_p .

At the start of the bonding, the two wafers 100 and 200 are each held pressed on the holding surfaces of their respective support plate (Figure 5C, Step S3).

Next, according to the invention, a curvature corresponding to the bonding curvature K_B which was calculated by means of Formula (6) given above, and which makes it possible to obtain the target post-bonding curvature K_{Fc} determined beforehand, is imposed on the first wafer 100 (or alternatively the second wafer) in order to induce a compensation radial misalignment D_{Rc} as described above (Figure 5D, Step S4).

To this end, the first support plate 310 comprises a jack or linear actuator 312 provided with a rod 313 which, when the jack is actuated, extends beyond the holding surface 311 of the plate 310 on which the first wafer 100 is pressed. As illustrated in Figure 5D, in this case the free end 313a of the rod 313 pushes on the first wafer, making it possible for a determined bonding curvature to be imparted to it. During the actuation of

the jack 312, the force of attraction of the holding means of the support plate 310, namely the suction force or the electrostatic force, can be controlled by the bonding machine so as to be reduced or even negated at the level of the central concentric region delimited on the holding surface 311 of the plate 310 so as to reduce the strains on the wafer during its curvature by the rod 313.

The bonding machine 300 controls the distance d_t over which the rod 313 projects beyond the holding surface 311, this distance d_t being determined as a function of the bonding curvature K_B to be imposed on the wafers. More precisely, the jack 312 is equipped with a servocontrol (not represented) which controls the linear position of the rod 313 as a function of a setpoint position defined by the bonding machine 300.

The bonding machine 300 is equipped with processing means, such as a programmable microprocessor, which are capable of calculating the bonding curvature K_B or a radius of curvature equivalent to the bonding curvature K_B , in the case of using a jack as in the machine 300 described here. More precisely, the initial curvatures K_1 and K_2 , respectively, of the wafers 100 and 200, as well as the target post-bonding curvature K_{Fc} are entered into the bonding machine, and the processing means of the bonding machine then calculate the bonding curvature K_B to be imposed by using Formula (6) given above and invert this value in order to obtain the corresponding target radius of curvature R_{cb} ($R_{cb}=1/K_B$).

The final parameter to be defined, which needs to be sent to the servocontrol of the jack 312, is the bow Δz corresponding to the radius of curvature R_{cb} , because as indicated above the bow of a wafer corresponds to the distance taken at the centre of the wafer between a reference plane, here the holding surface 311, and the surface of the wafer, here the surface of the wafer facing the holding surface 311. The bow Δz corresponds to the distance d_t over which the rod 313 must be extended when imposing the bonding curvature.

The target bow Δz_c as a function of the target radius of curvature R_{cb} may be calculated with the following formula:

$$\Delta z_c = R_{cb} - \sqrt{(R_{cb}^2 - (D/2)^2)} \quad (7)$$

where D is the diameter of the wafer to be curved.

Once calculated, the numerical value of the target bow Δz_c is transmitted to the servocontrol of the jack 312 which actuates the rod in order to position it at the equivalent distance d_t ($d_t = \Delta z_c$).

When the bonding curvature K_B is applied to the first wafer 100, the support plates 310 and 320 are moved towards one another so that the foremost portion 100a (apex) of the wafer 100 is delicately placed in contact with the exposed surface of the second wafer 200 so as thus to initiate the propagation of a bonding wave (Figure 5D, Step S5). The means for holding the second wafer 200 on its support plate 320 have been deactivated before or while bringing the two wafers into contact, in order to allow the second wafer 200 to adapt to the deformation (curvature K_c) imposed on the first wafer 100 during the bonding.

As an alternative, the two wafers may be placed at a distance Δz_c from one another and one of the two wafers may subsequently be deformed until the surfaces are brought in intimate contact by actuating the rod 313 over a distance $d_t = \Delta z_c$. Imposition of the bonding curvature K_B and initiation of the propagation of the bonding wave are thus performed simultaneously. In this case as well, the wafer which is not deformed to the predefined bonding curvature must be free to adapt to the bonding curvature imposed on the other wafer during the propagation of the bonding wave.

Molecular adhesion bonding is a technique well known per se. As a reminder, the principle of molecular adhesion bonding is based on bringing two surfaces in direct contact, that is to say without using a specific material (adhesive, wax, braze, etc.). Such an operation requires that the surfaces to be bonded are sufficiently smooth, and free of particles or contamination, and that they are brought sufficiently close together in order to make it possible to initiate contact, typically at a distance of less than a few nanometres. In this case, the attractive forces between the two surfaces are high enough to cause the propagation of a bonding wave which leads to molecular adhesion (bonding induced by all

the attractive forces (Van Der Waals forces) of electronic interaction between atoms or molecules of the two surfaces to be bonded).

Once the propagation of the bonding wave has been initiated, the second wafer 200, then released from its support plate 320, adapts to the curvature imposed on the first wafer 100 during the progression of the bonding wave (Figure 5E, Step S6).

When the two wafers are completely bonded, the first wafer 100 is completely freed from its support (Figure 5F, Step S7). A three-dimensional structure 400 is then obtained, which has the target curvature K_{Fc} defined beforehand.

It has thus been possible to compensate for the radial misalignment existing between the two wafers 100 and 200 by applying a predetermined bonding curvature. After the bonding, the microcomponents 110 remain correctly aligned with the microcomponents 210, despite the radial misalignment initially existing before bonding.

The curve in Figure 7 corresponds to measurements carried out on two wafers with a diameter of 300 mm and a thickness of 775 μm , each having two levels of metals and a bonding layer which is composed of a deposited oxide of the TEOS type and has been prepared. Figure 7 shows the variation of the radial misalignment as a function of the post-bonding curvature K_F of the wafers. It can be seen that for a post-bonding curvature K_F of approximately 0.005 m^{-1} , corresponding to a bow of approximately 55 μm , the initial radial misalignment has been entirely compensated. This curve shows clearly that, by adjusting the post-bonding curvature, it is possible to create an additional radial misalignment component which makes it possible to compensate for that of the initial radial misalignment existing between the wafers.

After the bonding, the structure 400 may be subjected to a moderate heat treatment (less than 500°C) so as to increase the bonding energy between the two wafers and allow one of them to be subsequently thinned.

As represented in Figure 5G, the first wafer 100 is thinned in order to remove a portion of material present above the layer of microcomponents 110 (Step S8). The wafer 100 may be thinned in particular by chemical-mechanical polishing (CMP), by chemical etching, or

by cleavage or fracture along a weakened plane formed beforehand in the substrate, for example by atom implantation. In the event that the first wafer is a substrate of the SOI type, as is the case here, the buried insulating layer may advantageously be used as a chemical etching stop layer in order to delimit the thickness of the remaining layer 100a. As an alternative, if the initial substrate is made of bulk material, deep zones, for examples zones of metallic material regularly spaced on the surface of the material, may be formed beforehand in it during the formation of the components in order to stop the mechanical thinning (polishing).

A three-dimensional structure 500 is then obtained, formed by the second wafer 200 and a layer 100a corresponding to the remaining portion of the first wafer 100.

According to an alternative embodiment, after formation of the microcomponents, an oxide layer, for example of SiO_2 , may be deposited on the surface of the first and/or lower wafer with a view to preparation for the bonding. This oxide layer or these oxide layers may furthermore be prepared by forming metal zones in them, for example of copper, in contact with all or some of the microcomponents in order to be able to bring the microcomponents of one wafer in contact with those of the other wafer.

The bonding faces of the wafers may furthermore be treated. The treatments employed for the surface preparation vary according to the bonding energy which is intended to be obtained. If the intention is to obtain a standard bonding energy, that is to say a relatively low one, the surface may be prepared by carrying out chemical-mechanical polishing followed by cleaning. Otherwise, if the intention is to obtain a high bonding energy between the two substrates, the preparation of the surface comprises cleaning of the RCA type (i.e. the combination of an SC1 bath (NH_4OH , H_2O_2 , H_2O) adapted to remove the particles and the hydrocarbons and an SC2 bath (HCl , H_2O_2 , H_2O) adapted to remove the metallic contaminants), surface activation by a plasma, and additional cleaning followed by brushing.

The bonding is preferably carried out at a controlled temperature in order to reduce the temperature difference between the two wafers.

The imposition of the bonding curvature may also be carried out with a bonding machine comprising a membrane interposed between the first wafer and the support for holding it, the membrane having a curvature corresponding to the said predefined bonding curvature, or with
5 a bonding machine comprising a holding support for the first wafer having a curvature corresponding to the said predefined bonding curvature, in which case the holding support may in particular be deformable and driven by the machine in order to adapt to the bonding curvature calculated beforehand by it. The contacting of the second wafer with the
10 first wafer and the release of the second wafer before initiation of the propagation of a bonding wave will be carried out as described above.

By virtue of the bonding method of the invention with compensation for the radial misalignment, it has been possible to bond the first wafer 100 (Top) onto the second wafer 200 (Base) without significant
15 offsets between the microcomponents 110 and 210. It is thus possible to limit the radial misalignments to negligible values homogeneously over the entire surface of the wafers. The microcomponents 110 and 210, even if they are of very small sizes (for example $< 1 \mu\text{m}$), can then be formed easily in alignment with one another. This makes it possible, for example,
20 to interconnect the microcomponents with one another by means of metallic connections, while minimizing the risks of bad interconnection.

CLAIMS

1. Method for bonding a first wafer (100) on a second wafer (200) by molecular adhesion, the said wafers having an initial radial misalignment (D_R) between them, the said method comprising at least a step of bringing the two wafers (100, 200) into contact so as to initiate the propagation of a bonding wave between the two wafers,

characterized in that a predefined bonding curvature (K_B) is imposed on at least one of the two wafers during the contacting step as a function of the initial radial misalignment (D_R).

2. Method according to Claim 1, characterized in that the second wafer (200) is free to adapt to the predefined bonding curvature (K_B) imposed on the first wafer (100) during the propagation of the bonding wave.

3. Method according to Claim 1 or 2, characterized in that the wafers (100, 200) are circular wafers of silicon with a diameter of 300 mm, each comprising microcomponents.

4. Method according to any one of Claims 1 to 3, characterized in that the method comprises the following steps before the bonding of the said wafers (100, 200):

- measurement of the initial radial misalignment (D_R) between the two wafers to be compensated,

- measurement of the curvature (K_1 ; K_2) of each wafer (100; 200) before bonding,

- determination of a compensation radial misalignment (D_{Rc}) for the initial radial misalignment (D_R) between the two wafers (100, 200),

- calculation of a post-bonding curvature (K_{Fc}) capable of generating the said compensation radial misalignment (D_{Rc}) between the two wafers,

- calculation of the predefined bonding curvature (K_c) as a function of the calculated post-bonding curvature (K_{Fc}).

5. Method according to Claim 4, characterized in that the post-bonding curvature is calculated using the following formula:

$$KF_c = DR_c/(h.R)$$

where KF_c is the post-bonding curvature, DR_c is the compensation radial misalignment, h is the thickness of the first wafer and R is the distance from the centre of the wafer to the measurement point of the radial misalignment.

6. Method according to Claim 4 or 5, characterized in that the predefined bonding curvature is calculated using the following formula:

$$K_B = (8KF_c - (K_1 + K_2))/6$$

where K_B is the predefined bonding curvature, K_1 is the initial curvature of the first wafer, K_2 is the initial curvature of the second wafer and KF_c is the post-bonding curvature.

7. Method according to any one of Claims 1 to 6, characterized in that it comprises the following steps:

- holding the first wafer (100) and the second wafer (200) facing one another respectively using a first holding support (310) and a second holding support (320), the said first support imposing the said predefined bonding curvature on the first wafer,

- bringing the said wafers (100, 200) in contact in order to initiate the propagation of a bonding wave between the said wafers,

- releasing the second wafer (200) from the second holding support (320) before or while being brought in contact with the first wafer (100), so that the said second wafer adapts to the bonding curvature imposed on the first wafer during the propagation of the bonding wave.

8. Method according to Claim 7, characterized in that the said predefined bonding curvature (K_c) is imposed on the first wafer (100) by actuating a jack (312) mounted on the first holding support.

9. Method according to Claim 7, characterized in that the said predefined bonding curvature is imposed on the first wafer (100) by a membrane interposed between the first wafer (100) and the first holding support (310), the said membrane having a curvature corresponding to the said predefined bonding curvature.

10. Method according to Claim 7, characterized in that the said predefined bonding curvature is imposed on the first wafer (100) by the first holding support (310), the said first holding support having a curvature corresponding to the said predefined bonding curvature.

11. Method according to any one of Claims 1 to 10, characterized in that the said wafers (100, 200) each comprise microcomponents (110; 210) on their respective bonding face, at least some of the microcomponents (110) of one (100) of the wafers being intended to be aligned with at least some of the microcomponents (210) of the other (200) wafer.

12. Apparatus (300) for bonding a first wafer (100) on a second wafer (200) by molecular adhesion, the said wafers having an initial radial misalignment (D_R) between them, the apparatus comprising a first and second holding support (310, 320) for respectively holding the first wafer (100) and the second wafer (200), characterized in that the said first holding support comprises means for imposing a predefined bonding curvature (K_c) on the said first wafer as a function of the initial radial misalignment, the apparatus controlling the second holding support (320) in order to release the second wafer (200) from the said second support before or while being brought in contact with the first wafer (100), so that the said second wafer (200) adapts to the bonding curvature imposed on the first wafer (100) during the propagation of a bonding wave.

13. Apparatus according to Claim 12, characterized in that it comprises processing means for calculating the predefined bonding curvature (K_c) as a function of the initial radial misalignment, or a radius

of curvature corresponding to the said predefined bonding curvature as a function of the initial radial misalignment (D_R).

5 14. Apparatus according to Claim 13, characterized in that the
said first holding support (310) furthermore comprises a jack (312)
capable of imposing the said predefined bonding curvature (K_c) on the
first wafer (100), the jack being driven according to a radius of curvature
corresponding to the said predefined bonding curvature (K_c), the
apparatus controlling the second holding support (320) in order to release
10 the second wafer (200) from the said second support after being brought
in contact with the first wafer (100), so that the said second wafer (200)
adapts to the bonding curvature imposed on the first wafer during the
propagation of a bonding wave.

15 15. Apparatus according to Claim 12, characterized in that the
said first holding support has a curvature corresponding to the said
predefined bonding curvature, or in that the said apparatus furthermore
comprises a membrane interposed between the first wafer (100) and the
first holding support, the said membrane having a curvature
20 corresponding to the said predefined bonding curvature (K_c).