

## **Processing for Bonding Two Substrates**

The invention relates to the technical field of bonding by molecular adhesion of two substrates to one another.

Bonding is one way to attach two substrates to each other, which finds application e.g. in the silicon-on-insulator fabrication technology called Smart Cut™. Bonding by molecular adhesion is a technique during which two substrates are brought in close contact to each other and wherein the surfaces properties of the substrates are such that they stick to one another, without the application of further adhesives. The process of bonding is specifically started by applying pressure locally to the two substrates which are placed in close contact, from where a bonding front then spreads out over the entire interface of the two substrates.

WO 2007/060145 discloses such a process for bonding by molecular adhesion. The bonding method described therein comprises, prior to bonding, a step consisting of modifying the surface state of one and/or the other of the substrates to be able to regulate the propagation speed of the bonding front. The surface state is modified by locally or uniformly heating the surface of one and/or the other of the substrates to be bonded. The heating serves to dissolve water from the surface of the substrates before bonding, which allows minimizing of bonding defects. Bonding defects are for example so called edge void defects which result from the presence of water at the interface. In the Smart Cut™ process this kind of defect can lead to the presence of non-transferred zones in the final product, e.g. a SOI wafer.

Nevertheless, even using the process of WO2007/060145, it has been observed that, in a fabrication line, the number of defects rises with the number of substrates bonded inside the bonding tool.

It is therefore the object of the present invention to provide a method with which the increase of bonding defects can be reduced.

This object is achieved with the method according to claim 1. Surprisingly, by providing, prior to bonding, a gaseous flow over the bonding surfaces of the substrate, the formerly observed increase of bonding defects could be stopped or at least reduced.

According to a preferred embodiment of the invention, the gaseous flow can be provided between the two substrates. In this case, a flushing of the surfaces can be carried out just until the substrates come into contact. By doing so, the beneficial effect of the gaseous flow can be even enhanced.

Preferably, the gaseous flow can be a laminar flow. It is believed that, by providing the gaseous flow, water which otherwise might saturate the atmosphere of a tool used for bonding, can be removed from the bonding surfaces. By providing the laminar flow, a possible re-entry of water due to turbulences can be prevented.

Advantageously, the flow can be essentially parallel to the bonding surfaces of the substrates. With this feature, the beneficial effect of water removal is further enhanced.

According to an advantageous embodiment, the gaseous flow can be provided during a heat treatment of the two substrates. By doing so, the water removal effect and as a consequence the bonding is improved.

Preferably, the gaseous flow can be heated such that the heat treatment is at least partially carried out using the heated gaseous flow. Thus, in addition to heating the substrates via radiation or conduction means, an additional convective heating can be provided.

According to a preferred variant, the heat treatment can be completely carried using the heated gaseous flow. In this case, the equipment necessary to carry out the heat treatment and/or the bonding do not need additional heating devices.

According to a preferred embodiment, the gaseous flow is stopped prior to the contacting of the two substrates. In other words, the gaseous flow is provided as long as the two substrates are not yet in contact so that the advantageous effects are achieved just until the bonding. Once the substrates are bonded, the gaseous flow is no longer necessary and is stopped to carry out the process in an economical way.

Preferably, the gas of the gaseous flow can have a thermal conductivity of better than  $10 \cdot 10^{-3} \text{ W/m.K}$ . The higher the thermal conductivity, the easier the gas can be heated up and

furthermore, the heat transferred to the substrates which further improves the overall process.

Advantageously, the gaseous flow can comprise nitrogen and/or an inert gas, in particular argon. In particular, the gaseous flow is constituted to at least 10% of one or more of these elements. Furthermore, Nitrogen has a sufficient high thermal conductivity of  $24 \cdot 10^{-3} \text{ W/m.K}$  and Argon has a thermal conductivity of  $T_c(\text{Ar}) = 16 \cdot 10^{-3} \text{ W/m.K}$ . In addition, depending on the mixture of the gas, e.g.  $\text{H}_2/\text{Ar}$ ,  $\text{Cl}_2/\text{Ar}$  or  $\text{F}_2/\text{Ar}$ , also hydrophobic surfaces can be bonded with reduced defects. Hydrophobic Si surface should be terminated by Si- dangling bonds and/or Si-H (low polar bonds), but also in case of  $\text{Ar}/\text{F}_2$  (10% $\text{F}_2$ ) gases, by a small portion of Si-F or  $=\text{Si}_{-F}^{\text{H}}$  bonds. Those bonds, though very polar, allow a bonding without water by  $=\text{Si}_{-H}^{\text{F}} \cdots \text{F} - \text{Si}$ ,  $=\text{Si} - \text{F} \cdots \text{H} - \text{Si}$  or  $=\text{Si}_{-H}^{\text{F} \cdots \text{H} - \text{F} \cdots \text{H} - \text{F} \cdots \text{H} - \text{F}} \cdots \text{H} - \text{Si}$  Bridging.

According to a preferred variant, the gaseous flow treatment can be carried out over a time period starting from seconds up to several minutes. In case an additional heat source is provided, a gaseous flow of just a couple of seconds is sufficient to achieve the desired results. Thus, the process can be run in a fast and reliable manner. On the other hand, the advantages of the process can also be achieved without an additional heat source by applying the process for a sufficient long time, typically of the order of minutes.

Preferably, the gaseous flow can have a temperature in a range from room temperature, thus typically  $19 - 24^\circ\text{C}$ , up to  $100^\circ\text{C}$ . With a gaseous flow in this temperature range, best results have been achieved over time.

Advantageously the gaseous flow can be provided in an oxidizing atmosphere, in particular Air or 20% $\text{O}_2$  in  $\text{N}_2$ , and/or a dry atmosphere with a low humidity rate.

The object of the invention is also achieved with the equipment for bonding two substrates to one another according to claim 14. The inventive equipment for bonding two substrates comprises the means to provide a gaseous flow, so that the same advantages as already described above for claim 1 can be achieved.

Preferably, the means to provide a gaseous flow can comprise a ventilation system and/or an aspiration system and/or one or more gas inlets. With such systems, the necessary gaseous flow can be provided in a simple and reliable manner.

Preferably, the means to provide a gaseous flow can be configured to provide a laminar gaseous flow. By doing so, like mentioned above, turbulences are prevented which could eventually lead to a re-entry of unwanted water molecules in the region of the substrates bonding surfaces.

According to an advantageous embodiment, the means to provide a gaseous flow can be configured to provide the gaseous flow essentially parallel to the substrate surfaces. In this configuration, optimized results can be achieved.

Preferably, the means to provide a gaseous flow further comprise a means to heat the gaseous flow, particularly to temperatures up to 100°C. By doing so, even more water can be removed from the bonding surfaces.

Advantageous embodiments of the invention will now be described in detail with respect to the following Figures:

Figures 1A – 1C illustrate the process step of a first embodiment according to the invention,

Figure 2 is a 3D schematic view illustrating the concept of the invention, and

Figure 3 illustrates a bonding equipment according to the invention.

Figures 1A – 1C illustrate three embodiments of the inventive process for bonding two substrates. The first step illustrated in Figure 1A consists in providing two substrates 1 and 3 within a bonding chamber 5. In this embodiment, substrates 1 and 3 are semiconductor wafers, in particular silicon wafers with or without additional layers provided thereon. They have either a semiconductor or insulating surface, like native oxide.

The two substrates 1 and 3 have been treated to have the necessary surface properties to be able to carry out bonding prior to entering the bonding chamber 5. In the chamber 5, the

two substrates 1 and 3 face each other with their respective bonding surfaces 7 and 9. They are held at a certain distance in parallel to each other. To be able to bond them, the bonding chamber 5 comprises a means (not shown) to move the two substrates 1 and 3 with respect to each other, so that they can be brought into contact with each other.

The next step of the inventive method is illustrated in Figure 1B. Part I of Figure 1B illustrates a first embodiment, Part II of Figure 1B, a second embodiment and Fig. III of Figure 1B a third embodiment.

According to the first embodiment, after the step of providing the two substrates (Figure 1A), the substrates are heated, e.g. using a lamp 11 or any other suitable heating means, like for example, providing inside the substrate holder (not shown). According to this embodiment of the invention, a gaseous flow 13, indicated by arrows, is provided between the two substrates 1, 3 and sweeps over the respective surfaces 7 and 9. Figure 2 illustrates this situation schematically in a three dimensional way. Figure 2 shows the two substrates 1 and 3 facing each other with the bonding surfaces 7 and 9. In between, the gaseous flow 13 is provided such that a non-confined atmosphere is created between the two substrates.

The provision of a non-confined atmosphere has the advantage that desorbed water from the surfaces 7 and 9 is trapped by the gaseous flow 13 and transported away from the substrates. This prevents a saturation of the atmosphere inside the bonding chamber 5 due to accumulation of water molecules from wafer to wafer. Therefore, the bonding quality can be kept constant as, from wafer to wafer, the necessary removal of water molecules from the surfaces 7 and 9 can be achieved. Typically, the gaseous flow is provided for a couple of seconds to achieve the desired effect.

In this embodiment, the gaseous flow is a laminar flow which prevents turbulences which could re-introduce water which has already been transported away. To further optimize the inventive process, the flow is provided parallel to surfaces 7 and 9 of substrates 1 and 3 like illustrated in Figure 2. The gaseous flow according to the embodiment consists of argon, nitrogen and/or any other inert gas or mixture thereof. In this embodiment, the temperature of the gaseous flow is about room temperature, which is typically in a range of 19°C - 24°C.

To provide a hydrophobic bonding a  $H_2/Ar$ ,  $Cl_2/Ar$  or  $F_2/Ar$  mixture in a pressure and temperature controlled chamber can be used.

Part II of Figure 1B illustrates a second embodiment of the invention. Elements with the same reference numeral as in Part I are not described in detail again, their description is incorporated herewith by reference.

The difference between the first and second embodiments is that, in the second embodiment, the bonding chamber 5 does not comprise a heating means 11 anymore. In this case, the gaseous flow 13, still at room temperature, is applied for a longer time, in particular for several minutes, to be able to eliminate about the same water quantity from the surfaces 7 and 9 of the wafers 1 and 3 as in the first embodiment. Thus in this embodiment, a simplified bonding chamber 5, not needing an additional heating device, can be used.

Part III of Figure 1B illustrates a third embodiment of the inventive method. Again, features having the same reference numerals as previously used are not explained in detail but their description is enclosed herewith by reference.

The difference of the third embodiment compared to the second embodiment is that, instead of using a gaseous flow 13 at room temperature, the gaseous flow 13' in this embodiment has a temperature higher than room temperature, in particular of up to 100°C. By doing so, it is again possible to remove the water from the surfaces 7 and 9 of substrates 1 and 3 while applying the gaseous flow 13' for a shorter time compared to the second embodiment and, at the same time, no additional heating device like in the first embodiment is needed.

For best results, the gaseous flow shall consist (at least to a percentage of 10%) of an inert gas or mixture thereof having a high thermal conductivity, such that the necessary heat transfer from the gas to the substrates 1, 3 can be optimized. Beside that, the features of the gaseous flow 13' correspond to the one of gaseous flow 13, in particular the gaseous flow shall be a laminar flow parallel to the surfaces 7 and 9.

Of course, embodiments 1 – 3 can be freely combined, for example, a gaseous flow 13' with a temperature higher than room temperature can be used in combination with a further

heating means 11, such that part of the heat treatment prior to bonding is provided by the gaseous flow and the remaining part by the heating means 11.

Figure 1C illustrates the third step of the inventive method which consists in bringing the two substrates 1 and 3 into close contact with each other to thereby start bonding. Bonding is typically initiated by local application of a light pressure followed by a bonding front which spreads out over the entire interface.

Just prior to the situation when the substrates 1, 3 touch each other, the gaseous flow between the substrates 1, 3 can be stopped.

The inventive method has the advantage that, it allows the removal of water absorbed on the surfaces of the substrates to be bonded in a reliable and repeatable manner compared to the prior art. Due to the reduced amount of water in the bonding interface, fewer bonding defects occur which in turn render the bonded substrate better in quality. The inventive process is of particular interest in the so called Smart Cut™ type process used to e.g. form silicon-on-insulator substrates for the electronics industry and which consists in transferring a layer from a donor substrate onto a handle substrate, wherein attachment between the donor substrate and the handle substrate is achieved by bonding.

In the above described embodiments one to three, the gaseous flow 13, 13' was provided inside the bonding chamber 5 between the two substrates 1 and 3 facing each other. According to a variant of the invention (not illustrated), the flushing of the bonding surfaces 7, 9 with the gaseous flow could also be carried out outside the bonding chamber 5 just before entering the substrates 1 and 3 into the chamber 5. In this configuration, it is also possible to sweep the surfaces 7, 9 individually, in parallel or one after the other. Furthermore, a non-confined atmosphere could also be achieved by moving the two substrates through an inert gas.

Figure 3 illustrates one embodiment of an inventive equipment for bonding two substrates. The bonding equipment 21 illustrated can serve as bonding chamber 5 like described above with respect to embodiments 1 – 3.

The bonding equipment 21 comprises a chamber 23. Inside the chamber, a substrate holder 25 is provided to hold the substrates 1 and 3 such that the bonding surfaces 7 and 9 face each other.

According to the invention, the bonding equipment 21 comprises a means 25a and 25b to provide a gaseous flow between the two substrates 1 and 3. In this embodiment, the means to provide a gaseous flow comprises a ventilation system 25a which provides the gaseous flow 13 which is then aspirated by an aspiration system 25b to remove the flow comprising water molecules desorbed from the surfaces of substrates 1 and 3.

As an alternative, instead of using a ventilation system 25a, one or more gas inlets could also be provided which are in connection with a corresponding gas supply. It is important to mention that the means to provide the gaseous flow is preferably arranged and configured such that the gaseous flow 13 is a laminar flow, the advantages of which are described above. Furthermore, the means to provide the gaseous flow are preferably configured such that the flow 13 is parallel to the substrate surfaces. According to a variant, the ventilation system 25a could also be designed to have two or more gaseous flows coming from several directions.

Depending on the process carried out (see part I of figure 1B), the bonding equipment can furthermore comprise heating means 27, e.g. a lamp which could be located upon the center or the edge of the wafer to heat locally or totally the surfaces of the wafer to be bonded.

### Claims

1. Method for bonding two substrates, in particular two semiconductor substrates, to one another, wherein prior to bonding a gaseous flow (13) is provided over the bonding surfaces (7, 9) of the substrates (1, 3), wherein the gaseous flow (13) is provided between the two substrates (1, 3), until the substrates come into contact.
2. Method according to claim 1, wherein the gaseous flow (13) is a laminar flow.
3. Method according to one of claims 1 or 2, wherein the flow (13) is essentially parallel to the surfaces (7, 9) of the substrates (1, 3).
4. Method according to one of claims 1 to 3, wherein the gaseous flow (13,13') has a temperature in a range from room temperature up to 100°C.
5. Method according to one of claims 1 to 3, wherein the gaseous flow (13, 13') is provided during a heat treatment of the two substrates (1, 3).
6. Method according to claim 5, wherein the gaseous flow (13') is heated such that the heat treatment is at least partially carried out using the heated gaseous flow (13').
7. Method according to claim 6, wherein the heat treatment is completely carried out using the heated gaseous flow (13').
8. Method according to one of claims 1 to 7, wherein the gas of the gaseous flow (13) has a thermal conductivity of  $10 \cdot 10^{-3}$  W/m.K
9. Method according to one of claims 1 to 8, wherein the gaseous flow (13) comprises nitrogen and or/an inert gas, in particular Argon.
10. Method according to one of claims 1 to 9, wherein the gaseous flow treatment is carried out over a time period starting from seconds up to several minutes.

11. Method according to one of claims 1 to 10, wherein the gaseous flow is provided in an oxidizing atmosphere, in particular Air or 20%O<sub>2</sub> in N<sub>2</sub>, and/or a dry atmosphere with a low humidity rate.
12. Equipment for bonding two substrates (1, 3) to one another comprising a means (25a, 25b) to provide a gaseous flow (13) between the two substrates (1, 3), wherein the means (25a, 25b) to provide a gaseous flow is configured to provide a laminar gaseous flow.
13. Equipment according to claim 12, wherein the means to provide a gaseous flow comprises a ventilation system (25a) and/or an aspiration system (25b) and/or one or more gas inlets.
14. Equipment according to one of claims 12 to 13, wherein the means (25a, 25b) to provide a gaseous flow is configured to provide the gaseous flow (13) essentially parallel to the substrate surfaces (7, 9).
15. Equipment according to one of claims 12 to 14, wherein the means (25a, 25b) to provide a gaseous flow further comprises a means (27) to heat the gaseous flow, in particular up to 100°C.