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(54) Title: EQUIPMENT FOR WAFER BONDING

(57) Abstract: Equipment and a process for performing in-situ wafer surface activation, precision alignment of features on each wafer and bonding of the wafers in the same apparatus. The direct bonding part of this processes optionally includes apparatus for the controlled contacting of wafers in order to ensure single point bond initiation without any tooling contact on the surfaces to be bonded.



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Equipment for Wafer Bonding

Description

This invention concerns the various steps required during the direct bonding of wafers. The invention will be described in terms of bonding silicon wafers but the principle applies no matter what material is used. By direct bonding we mean the process by which two highly polished surfaces are pulled into intimate contact by surface forces, eg Van der Waal's or hydrogen bonding. This process was first described by Lord Raleigh in 1936! However it is only in recent years that the technique has found commercial application and is now commonly used as a fabrication step in the fabrication of silicon-on-insulator (SOI) wafers for microelectronics and as a means of achieving more 3-dimensional capability within micro-electro-mechanical devices (MEMS).

The invention also covers the various steps required during the aligned bonding of wafers using low temperature direct bonding processes. By "low temperature direct bonding" we refer to processes such as those described in patent US 6,645,828 whereby plasma activation of the wafer surfaces is used to significantly reduce the subsequent annealing temperature required to produce a high strength bond between the two bonded wafers.

Existing equipment for performing an aligned low temperature direct bond consists of the following:

- (a) A process chamber for performing the required surface activation
- (b) An aligner for aligning the wafers and holding them in aligned contact
- (c) A bond chamber for contacting and heating the wafers to produce a full strength bond.

In some cases items (a) & (c) or (a) & (b) are combined but this still means that the wafers have to be transferred from one piece of equipment to another in order to perform the full process. It would be desirable if the process steps defined in items (a) to (c) above could all be carried out in a single machine. This would minimise wafer handling and importantly, would also prevent exposure of the activated wafers to the ambient atmosphere in the period between surface activation and contacting.

Accordingly this invention provides a means of performing steps (a) to (c) in a single machine. This machine will now be described with reference to the accompanying drawings. The machine shown schematically in Figure 1 consists of a chamber (1), a means (2) of manipulating the wafers in three linear axes, x, y & z, and rotation about the z axis, a means (3) for activating the surfaces of the wafer, and an optical system (4) for viewing the wafers whilst they are in the chamber. The wafers (5) and (6) are located on upper platen (7) and lower platen (8). The process is carried out as follows:

Two wafers (5 & 6) are loaded into the machine that can then be evacuated to produce a reduced pressure, and / or filled with a gas to provide a specific gaseous environment inside the chamber. The upper wafer (5) is fixed to the upper platen (7) and is oriented with the surface to be bonded facing downwards. The lower wafer (6) is located on the lower platen (8) and is oriented with the surface to be bonded facing upwards.

plasma elsewhere in the chamber and using the gas flow, determined by the position of the port 9 to an external pump, to cause the excited atoms and charged ions that are produced in the remote plasma to pass over the wafer surfaces thereby producing the required surface activation to enable the wafers to subsequently be bonded using a low temperature (typically ~200°C). In addition other techniques such as UV, corona, energetic ions, etc can be used, the in-situ process being compatible with all these forms of activation.

Having activated the surfaces the wafers are then aligned in-situ. This is accomplished by mounting the lower wafer on a moveable (XYZ θ) stage and holding the other wafer upside down in the vacuum chamber. AML has a special wafer clamp arrangement (described in a separate patent application) that uses a spring-loaded knife edge 10 to achieve this upside down mounting without any part of the fixture protruding above the surface of the wafer. The external optics can be used to see, via viewports in the chamber lid, the alignment marks on the two wafers. For IR alignment, two IR sources 11 are fitted in the appropriate positions beneath the lower wafer.

Once the wafers are aligned then the Z drive is used to bring them into contact and to apply force. This produces a bonded interface strong enough for the wafers to then be removed from the chamber. Storage at room temperature for 24 hours, or a low temperature anneal, eg 2 hours at 300°C, results in a high strength bond. Optionally this heating can also be performed in-situ.

Although the direct bonding step can be performed with flat platens, it is preferable for the bond to be initiated at a single point.

Tools for performing direct bonding, and ensuring a single bond initiation point, are commercially available and all work in a similar fashion. Referring to Figure 2, the two wafers (12) and (13) to be bonded are mounted in a machine such that the two faces (14) and (15) that require bonding are facing each other. If the wafers were brought into contact without any additional steps being taken then, unless they were perfectly flat and polished to a sub-nm surface finish, they would only actually touch at a few locations. These initial location points would act as the starting points for the surface forces to pull the wafers into intimate contact. We can call this progression of the contact region, from each point, a bond front. The problem with this process is that the multitude of bond fronts results in some of the bond fronts intersecting and this can result in the generation of a non-bonded region, commonly referred to as a void.

In order to overcome the formation of voids it is preferable to control the wafer contacting process such that there is only a single initial contact point, usually but not necessarily, at the centre of the wafer. To achieve this controlled wafer contacting, existing equipment utilises "flags" (16) which are inserted at, normally, three locations around the wafer edges. These flags that are typically about 0.1mm thick and protrude about a millimetre in from the wafer edge, serve to keep the two wafers a set distance apart.

In order to contact the wafers a push-pin or rod (17) is then used to deform one of the wafers such that the centre of the deformed wafer is brought into contact with the other wafer. This situation is shown in Figure 3. Once this contact has been made the flags can be withdrawn (as indicated by the arrows) and a single bond front then propagates out radially from the central initiation point, thus preventing the occurrence of voids.

Although this process works well, it does have problems associated with it. For example, it is often desirable in wafer processing for both MEMS and microelectronics processing to avoid

mechanical contact with the surfaces to be bonded. Resultant issues such as scratches and the generation of particles can affect yields. In addition, the inclusion of a mechanism for inserting and removing the flags increases the machine complexity, plus the thin flags are prone to failure.

Accordingly, this invention describes a method for achieving the controlled initiation of a single bond front using a "flag-less" system. Referring now to Figure 4, wafers (12) and (13) are arranged to face each, but instead of flags being used to control the separation of the two wafers, the lower wafer (12) rests on a platen (18) that can be moved in a controlled manner in the Z direction, ie perpendicular to the wafer plane. The upper wafer (13) is held on a second platen (19) that incorporates an edge clamping system that holds the wafers in place. This edge clamping system typically consists of three knife-edges, two fixed (20) and one spring-loaded (21), although other quantities of knife-edges, and combinations of fixed vs spring-loaded knife edges can be used. A typical spring force for the spring-loaded knife-edge is 350g but other values can be used.

To mount the wafer the spring-loaded knife-edge is withdrawn (as indicated by the arrows) and once the wafer is in place then the spring-loaded knife-edge is released such that the spring force acts on the wafer edge (22). Referring now to Figure 5 that shows a magnified view of the wafer edge (22) it can be seen that the wafer edge has a "C" shape. This shape is standard for silicon wafers, and many other wafer materials including glass, and is defined as an industry standard by SEMI (Semiconductor Equipment & Materials International). This standard shape helps to support the wafers when using the wafer clamping system described here. Provided that the height of the knife-edges (20) & (21), with respect to the platen (19) is greater than 50% of the wafer thickness, then the knife edges not only support the wafer via the spring force, but provide a "ledge" on which the wafer sits without actually making any contact to the surface (15) to be bonded.

Having secured the wafer (15) it is now necessary to deform it such that the central part is made to contact the other wafer (14) in a single point, preferably but not necessarily, in the centre. To achieve this a further spring-loaded pin (23), or a pin that can be actuated (in the direction indicated by the arrows) by any other means (eg shape memory alloy, bimetallic, piezoelectric, electromechanical, etc) is fixed into the platen (19). This pin is then used to deform the wafer (13) by a fixed amount, typically about 0.1mm. The other platen (18) is then raised and a force applied that is gradually increased such that it overcomes the force acting on the spring pin (23). In this way the contact area of the two wafers is increased in a controlled manner until full area contact is achieved when the spring-pin (23) is fully compressed. Typically the spring-pin force is about 100N but can be adjusted to suit wafers of different thickness. The force available through the lower platen (18) is much higher than this and in some instances, eg to overcome various warps, hollows, rough areas, etc in either of the two wafer surfaces to be bonded, it may be necessary to apply many kN.

To assist with the controlled bonding of wafers with regions that are more difficult to bring into intimate contact, an alternative to the plane platen (18) can be used. This alternative, known as a pin chuck, is described in Figure 6. It consists of an array of spring-loaded pins (24). Three (25) of these pins are located at a height which is above the remainder. These three pins are supported by very weak springs (26) (~10N) and the wafer (12) to be bonded sits on these pins. The rest of the pins are each supported by a much stronger spring (27), typically 100N each, and the heights of these pins can be controlled by pre-loading the springs on the rods. In this manner a controlled profile of pin heights can be obtained. Normally the profile would be adjusted to give a peak at

the centre. Thus the bond front propagates from the centre outwards in a similar manner as for the case of the flat platen, but in the case of the pin chuck the profiles can be adjusted such that force can be concentrated in a region for which additional force is required in order to overcome a particular surface feature, eg depression in the surface of one of the wafer to be bonded.

Wafer bonding using the pin chuck works as follows: The three weak springs (25) are levelled such that the wafer (12) can be made parallel to the other wafer (13). The pin chuck is then raised until the two wafers (12) and (13) are in close proximity. Micromanipulators (not shown in the drawings) in the X and Y axes, plus rotation are then used to align the patterns that exist on the two wafers. The wafers are then brought into contact and at this point the highest pin in the array (27) contacts the wafer (12) and starts to work against the opposing spring (23). As the wafer(13) is flattened further pins in the array (27) start acting on the wafer (12) such that the bond front propagation proceeds outwards from the initiation point in a controlled manner

The tooling described above represents an improvement in the available technology for controlling the direct bonding of wafers. The set of tools described, ie edge clamp, spring-pin, and pin chuck, can all be used together for "difficult to bond" wafers, or the edge clamp and spring-pin can be used with a standard flat platen for more ideal wafers. For both cases the drawbacks previously described when using a flag-based system are overcome.

In some circumstances it is also beneficial to include a heaters in the platens (18) and (19), or the pin array (24) so that once contacted, the bond strength between the wafers can be increased in-situ via heating.

Claims

1. A wafer bonding apparatus whereby activation, alignment and bonding are all performed in-situ.
2. Apparatus for direct bonding of two, or more, wafers whereby one wafer can be bowed in a controlled manner, without the inclusion of any material (commonly known as flags) between the wafers, such that the bonding is initiated in a defined position on the wafers.
3. Apparatus as per claim 1, whereby the activation, alignment and bonding is performed in the same chamber.
4. Apparatus, as per claim 1, whereby the activation, alignment and bonding is performed in vacuum
5. Apparatus, as per claim 1, whereby the activation, alignment and bonding is performed in a defined gas pressure.
6. Apparatus, as per claim 1, whereby the activation, alignment and bonding is performed in a combination of vacuum and gaseous ambients.
7. Apparatus, as per claims 5 and 6, whereby the gas is oxygen, nitrogen, inert gas such as argon, a hydrocarbon, compound gases or any mixture of the above, including air.
8. Apparatus, as per claim 1, whereby the activation process is performed on either, or both, wafers.
9. Apparatus, as per claim 1, whereby the activation is performed via a plasma treatment.
10. Apparatus, as per claim 1, whereby the activation is performed via any other means of activating a surface such as, but not limited to UV, or other frequency electromagnetic radiation, energetic ions, corona discharge, ect.
11. Apparatus, as per claim 1, whereby the source of the activation energy is remote from the wafers.
12. Apparatus, as per claim 1, whereby the alignment is achieved by moving one wafer in relation to the other wafer before bringing them into contact.
13. Apparatus, as per claim 1, whereby the alignment process is achieved using visible light for viewing / imaging the alignment features.
14. Apparatus, as per claim 1, whereby the alignment process is achieved using infra red light for viewing / imaging the alignment features.
15. Apparatus as per claim 14 whereby the IR light, used for alignment, is transmitted through the platens, or wafer chuck.
16. Apparatus, as per claim 2, whereby the wafer bow is achieved via a pin that applies a force to the back surface of at least one of the wafers whilst the wafer is held at the edges, with no contact to the surface to be bonded.
17. Apparatus as per claim 2, whereby heaters are included such that the bond strength of the wafers can be increased via in-situ heating.
18. Apparatus, as per claim 15 whereby a variable force, and protrusion, can be applied on the pin depending on the thickness of the wafer being bonded.
19. Apparatus, as per claim 15 whereby the edge clamping is achieved using spring-loaded pins.
20. Apparatus, as per claim 15 whereby the force on the edge clamping pins is produced by mechanical, pneumatic, hydraulic, electromagnetic or other actuation .
21. Apparatus, as per claim 15 whereby the edge pins act at points below the centre point of the standard SEMI specification "C" edge on the wafer being bonded.
22. Apparatus for direct bonding whereby one of the platens, or wafer chucks, consists of an array of spring-loaded pads.

23. Apparatus as per claim 19 whereby to enable precision alignment and avoid movement during wafer contact, three of these pads are located at a height which is above the remainder. These three pads are supported by very weak springs and one of the wafers to be bonded sits on these pads. The rest of the pads, that control the bond propagation, are each supported by a much stronger spring, and the heights of these pads can be controlled by pre-loading the springs on the rods. In this manner a controlled profile of pad heights can be obtained.
24. Apparatus as per claim 20 whereby the height profile of the pads is adjusted to give a peak at the centre.
25. Apparatus as per claim 20 whereby the height profile of the pads is adjusted to give a peak in a region for which additional force is required in order to overcome a particular surface feature, eg depression in the surface of one of the wafers to be bonded.

Figure 1.

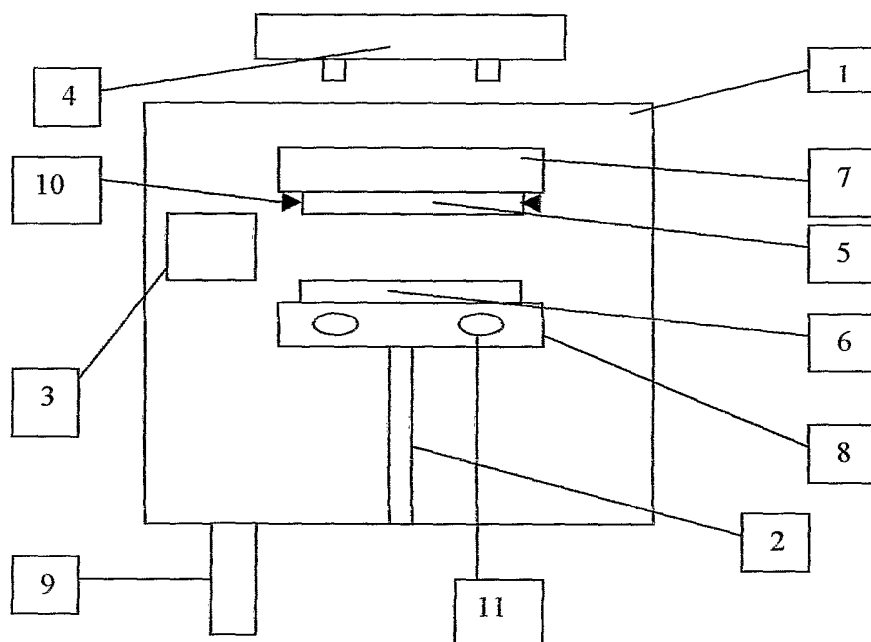


Figure 2.

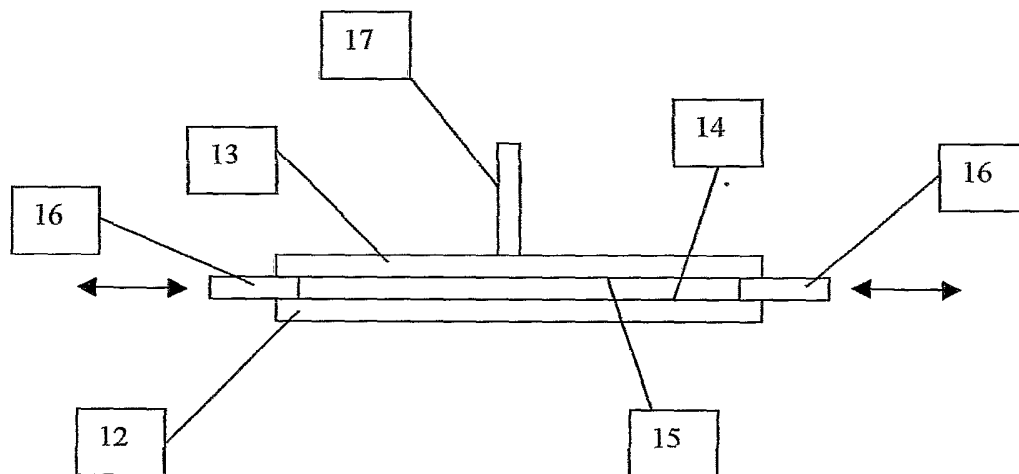


Figure 3.

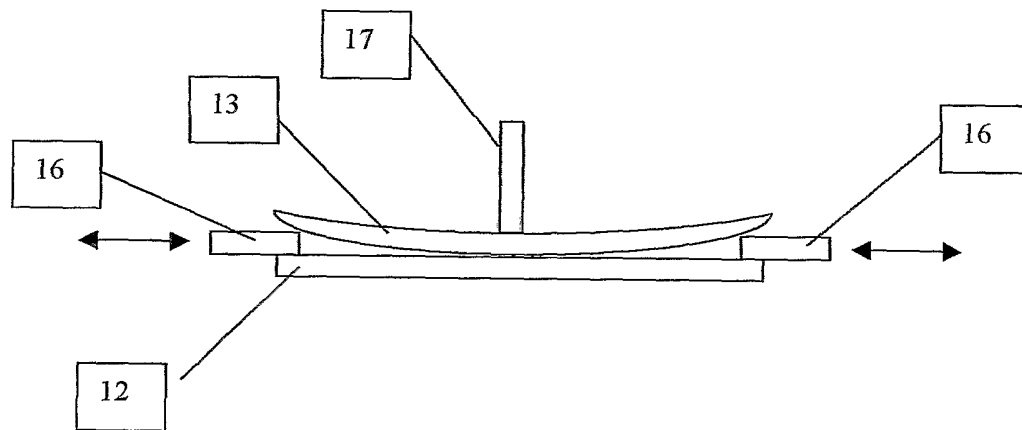


Figure 4.

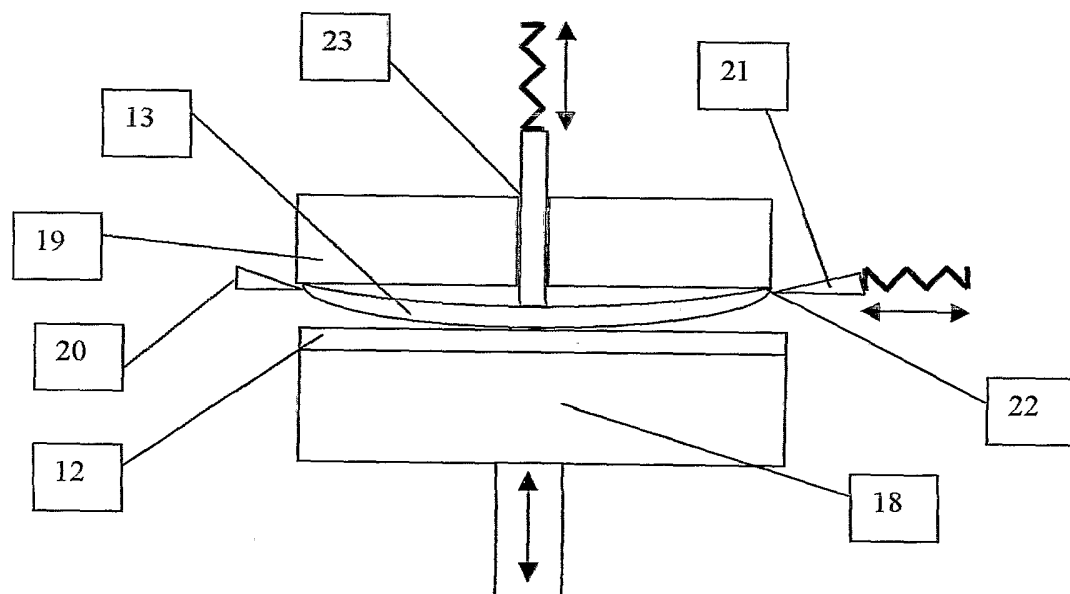


Figure 5.

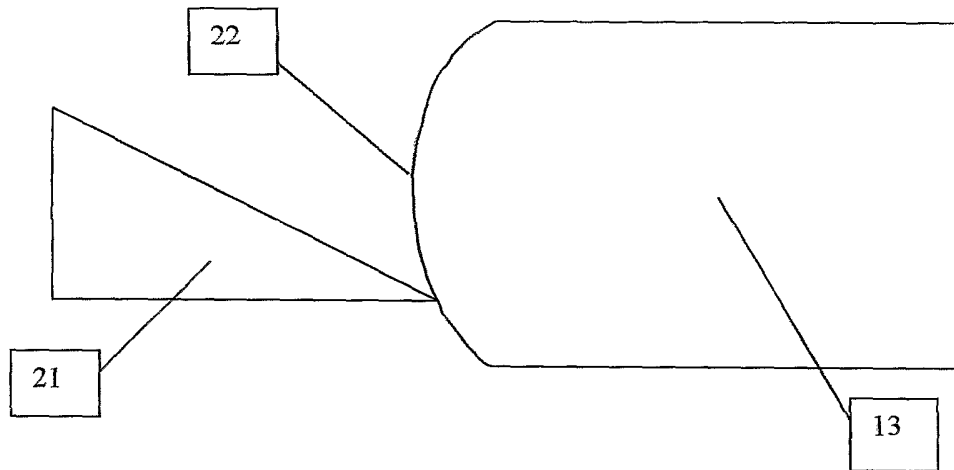


Figure 6.

