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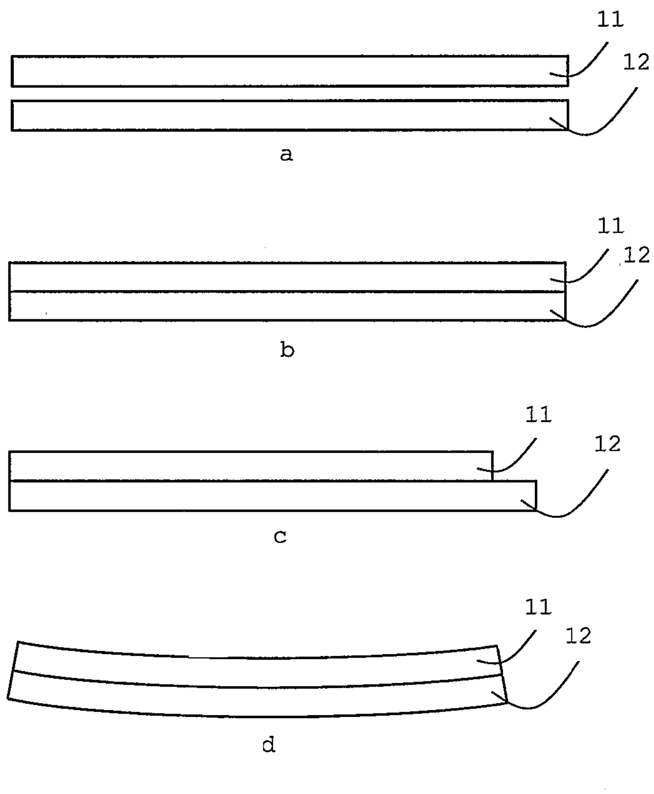
(54) Title: A BONDING SYSTEM HAVING STRESS CONTROL



(57) Abstract: An approach where items of different temperatures are bonded to each other such that upon cooling down they contract in size resulting in zero residual stress between the bonded items at an ambient temperature. If materials of the bonded items have different thermal expansion coefficients and the items are put together at different bonding temperatures, then they may have insignificant residual stress upon cooling down to the ambient temperature (e.g., room temperature) because the different ranges of the temperature drops compensate for the different contractions.

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A BONDING SYSTEM HAVING STRESS CONTROL

Background

The present invention pertains to MEMS (micro electro mechanical systems) technology, and particularly to wafer-to-wafer bonding. More particularly, the invention pertains to stress-related bonds.

Summary

The invention involves controlling the residual stress in a bonded wafer. Usually the goal is to minimize or virtually eliminate residual stress in wafer bonds.

Brief Description of the Drawings

Figures 1a, 1b, 1c and 1d reveal a stress-impacted bonding of two wafers;

Figures 2a, 2b and 2c reveal a stress-free bonding of two wafers; and

Figure 3 reveals a bonder for implementing stress-free bonds between wafers.

Description

Anodic bonding is a method of joining glass to silicon without the use of adhesives. The silicon and glass wafers may be heated to a temperature (typically in the range 300 to 500 degrees C depending on the glass type) at which the alkali-metal ions in the glass become mobile. The components may be brought into contact and a high voltage applied across them. This causes the alkali cations to migrate from the interface resulting in a depletion layer with high electric field strength. The resulting electrostatic attraction brings the silicon and glass into intimate contact. Further current flow of the oxygen anions from the glass to the silicon may result in an anodic reaction at the interface in that the glass becomes bonded to the silicon with a permanent chemical bond.

Anodic bonding, a fabrication technique commonly used in MEMS fabrication and used, in particular, for MEMS gyroscopes and accelerometers, typically results in residual stress in the bonded wafers and devices. Since the wafers are different materials, they have different rates of thermal expansion. Therefore, when the resultant bonded wafer is cooled from the bonding temperature, the two materials bonded to each other in the wafer contract at different rates resulting in significant residual stress. The temperature differential technique may be used for various types of attachment and bonding. The residual stress may be minimized or nearly eliminated. For instance, the wafers may be held at slightly different temperatures during bonding. Upon cooling down, the bonded wafers may contract at different rates and result in having an insignificant amount of residual stress between the wafers at ambient or room temperature.

Anodic bonding may be used in MEMS for joining one wafer to another, or for bonding a chip to a package (such as a glass enclosure). In general, anodic bonding may be used to join a metal or semiconductor to glass. In MEMS, the semiconductor may be silicon and the glass may be Corning 7740 (i.e., Pyrex™), Hoya SD2, or the like.

Anodic bonding is an illustrative example. There are various other wafer bonding techniques, such as "fusion" or "direct" bonding, frit bonding, eutectic bonding, and the like, which may be used with the present bonding system having stress control at the interface of the bonded materials.

One concern with bonding in general is that two different materials (e.g., silicon and Pyrex™) may be bonded at an elevated temperature, typically from about 300 to 500 degrees C. The materials may be heated up, bonded together, and then cooled back down to room temperature. As the combined materials (i.e., in a wafer or device) cool down, the difference between the thermal expansion of the two materials may result in a stress between the two materials attached to each other. When the materials are in wafer form, the stress may cause the resultant wafer to bow significantly. When the fabrication is complete, there may be a residual stress that remains between the glass portion of the device and the silicon portion of the device. Such stress may lead to layout difficulties, device performance problems, long term drifts, and/or poor reliability.

It would be desirable to bond two different materials that have exactly the same thermal expansion over the entire temperature range during bonding and device operation. However, no such two different materials appear to exist. Pyrex™ is regarded as thermally matching quite well with silicon. Despite these close thermal expansions, there still may be notable stress between the materials after bonding. Glass such as Hoya™SD2 may be a better match for silicon. However, for various reasons, Pyrex™ could be the material of choice for bonding with silicon. Thus, bow and residual stress may be always present.

The invention is an approach for achieving a bond with virtually no residual stress at room temperature. An example bond may be between two materials such as silicon wafer 11 and Pyrex™ wafer 12. The room temperature stress may be changed by holding the silicon wafer 11 at one temperature and the Pyrex™ wafer 12 at a different temperature at bonding time. One reason this approach works is because different differentials or changes of temperatures between bonding and a cooled-off state may compensate for the different coefficients of thermal expansion. Wafer 11 and wafer 12 at a bonding temperature (much higher than room temperature) may be matched in length before bonding (Figure 1a). Since the wafers 11 and 12 are at the same temperature and not constrained during heating, they may be stress free when first bonded together (Figure 1b). As the wafers 11 and 12 cool down to room temperature, they may contract. If they are bonded well to each other, the wafers 11 and 12 may contract to shorter lengths. However, even though the lengths of wafers 11 and 12 were the same at the bonding temperature, the wafers may contract to different lengths at room temperature because of the different coefficients of thermal expansion of silicon and Pyrex™ (Figure 1c).

If α_1 is the thermal expansion coefficient of wafer 11, then as the wafer cools it may contract by an amount of $\Delta L_1 = \alpha_1 L_1 \Delta T$. Similarly, wafer 12 may contract by an amount $\Delta L_2 = \alpha_2 L_2 \Delta T$. Since $L_1 = L_2$ when the wafers are at bonding temperature, the amount of contraction may differ between wafers 11 and 12 in that $L_1 \neq L_2$ when the wafers are at room temperature. However, if the wafers are bonded to each other, they may be constrained to contract by the same amount. The resultant constraint may lead to a residual stress and bow of the wafers 11 and 12 (Figure 1d).

One may use a simplification that the thermal expansion coefficient does not change with temperature. In reality, the thermal expansion coefficient generally does change with temperature, but the conclusions would be still the same as if one used the simplification. The thermal expansion coefficient may be defined as $\alpha = (1/L)(\Delta L/\Delta T)$, where L is the length of the sample, and ΔL is the length change when the temperature changes by ΔT. Examples of linear thermal coefficients of expansion α_1 and α_2 for silicon and Pyrex™ glass may be 3 and 4 parts per million per Celsius degree, respectfully.

For a silicon wafer having a length of ten centimeters, a room temperature of 20 degrees C and a bonding temperature of 420 degrees C, $\Delta L_1 = \alpha_1 L_1 \Delta T = 3 \times 10^{-6}$ ppm x 10 cm x 400 deg C = 1200×10^{-5} cm = 1.2×10^{-2} cm. For a Pyrex™ glass wafer having a length of ten centimeters, a room temperature of 20 degrees C and a bonding temperature of 420 degrees C, $\Delta L_2 = \alpha_2 L_2 \Delta T = 4 \times 10^{-6}$ ppm x 10 cm x 400 deg C = 1600×10^{-5} cm = 1.6×10^{-2} cm. The difference of expansions may be $\Delta L_2 - \Delta L_1 = 4 \times 10^{-3}$ cm.

Next, one may note a case where wafers 11 and 12 are held at two different temperatures for and during bonding. Then the temperature changes upon cooling of wafers 11 and 12 from the bond temperatures to the room temperature, respectively, may be different. So the applicable formulas may be $\Delta L_1 = \alpha_1 L_1 \Delta T_1$ and $\Delta L_2 = \alpha_2 L_2 \Delta T_2$.. As noted before, $L_1 = L_2$, but temperatures of wafers 11 and 12 may be chosen such that $\alpha_1 \Delta T_1 = \alpha_2 \Delta T_2$ or $\alpha_1 \Delta T_1 \approx \alpha_2 \Delta T_2$ and thus $\Delta L_1 = \Delta L_2$ or $\Delta L_1 \approx \Delta L_2$, respectively. In Figure 2a, wafer 11 may be at T_1 and wafer 12 at T_2, where T_1 and T_2 are the bonding temperatures before bonding. In Figure 2b, the bonding temperatures T_1 and T_2 may be maintained while the wafers 11 and 12 are bonded to each other. As the temperature is reduced from the bonding temperature in Figure 2b to an ambient, pre-bonding, operating, storage, normal, or room temperature after bonding in Figure 2c, each wafer undergoes the same length change and thus there is no residual stress in and no bowing of the bonded wafer pair at room temperature.

The bonding temperatures difference between wafers 11 and 12 is not necessarily large. Such temperature difference may be achieved with bonding equipment.

The approach may be more complicated if the thermal expansion coefficients are temperature dependent. This may make the mathematics more involved, but the extensive calculation would not generally qualitatively change the result. While the desire may typically be to achieve minimum stress at room temperature, the present approach may also be used to achieve any targeted, nonzero stress in the combined wafers 11 and 12. The concept remains the same. The starting temperatures just before bonding may be adjusted appropriately to get the targeted stress.

Wafer bonders may be equipped with a heater on both the top side and the bottom side of the wafer stack. The heaters may be independently controlled, allowing the temperatures of the top and bottom wafers to be set independently. Further, bonding the wafers in a vacuum may reduce the thermal contact between the wafers, thus making it easier to vary the wafer temperatures independently than if the wafer bonding were done in an air environment.

The above-described bonding approaches may be applied to many kinds of devices and products. Examples may include MEMS gyroscopes, MEMS accelerometers, MEMS inertial measurement devices, non-MEMS devices, and so forth.

In Figure 3 is a bonder 15 that may be in an enclosure 16. Enclosure 16 may be capable of holding bonder 15 in a vacuum. A holder 17 may secure wafer or item 11 into a position with a clamp 25. Holder 18 may secure wafer or item 12 into a position with a clamp 26. Clamps 25 and 26 may hold wafers 11 and 12, respectively, at the edges so that the facing surfaces of wafers 11 and 12 can come in contact without interference. Clamps 25 and 26 may be spring-loaded, or otherwise, so as to maintain an appropriate grasp on the wafers when they expand or contract. Clamps 25 and 26 are such that the wafers may be grasped and released with ease either manually, pneumatically, mechanically or electronically.

Item 11 may be heated to a bonding temperature T_1 by a heater element 21. Item 12 may be heated to a bonding temperature T_2 by a heater element 22. T_1 may be sensed by a temperature sensor 23 and T_2 may be sensed by a temperature sensor 24. Actuator 27 may have an arm 28 attached to holder 17 to move holder 17 towards or away from wafer holder 18 so as to bring wafers 11 and 12 together for bonding, or apart prior to bonding for placement of the wafers, or after bonding for release of the bonded wafers.

An electronics module 29 in bonder 15 may be an interface between bonder 15 and computer/processor 31. Computer or processor 31 may be programmable so that the wafers or item 11 and 12 may be bonded resulting in a predetermined amount of stress between them at an ambient, pre-bonding, operating, storage or room temperature after bonding. The predetermined amount of stress may be selected to be insignificant or virtually zero. The heaters 21 and 22, temperature sensors 23 and 24, and actuator 27 may be connected to the computer or processor 31 via electronics 29, or electronics 29 may be designed so as to control the temperature of the wafers or items 11 and 12 for bonding. In lieu of the computer or processor 31, electronics 29 may be designed to be programmable for setting the amount of stress desired between the resultant bonded wafers or items 11 and 12. Certain external controls may be connected to electronics

29 for user interfacing. Electronics 29 may be situated in or attached to a base 32 along with holder 18 and actuator 27.

In the present specification, some of the material may be of a hypothetical or prophetic nature although stated in another manner or tense.

Although the invention has been described with respect to at least one illustrative embodiment, many variations and modifications will become apparent to those skilled in the art upon reading the present specification. It is therefore the intention that the appended claims be interpreted as broadly as possible in view of the prior art to include all such variations and modifications.

What is claimed is:

1. A method for bonding comprising:

providing a first material;

providing a second material;

heating the first material to a first temperature; and

heating the second material to a second temperature; and

wherein:

the change in size of the first material from a room temperature to the first temperature is a first percentage;

the change in size of the second material from the room temperature to the second temperature is a second percentage; and

the second percentage is approximately the same as the first percentage.

2. The method of claim 1, wherein the first and second temperatures are sufficient for bonding the first and second materials.

3. The method of claim 2, wherein the first and second materials are bonded to each other while maintaining the first and second temperatures, respectively.

4. The method of claim 3, further comprising cooling the first and second materials to a third temperature.

5. The method of claim 4, wherein:

a bonding of the first and second materials results in a multi-layer wafer; and

the third temperature is an operating temperature of the multi-layer wafer.

6. The method of claim 5, wherein the first and second materials have different thermal expansion coefficients.

7. The method of claim 5, wherein:

the first material is silicon; and

the second material is glass.

8. The method of claim 7, wherein the glass is Pyrex™.

9. The method of claim 7, wherein the glass is Hoya™ SD2.

10. The method of claim 6, wherein the first and second materials are MEMS materials.

11. A means for bonding comprising:

means for heating a first material to a first temperature;

means for heating a second material to a second temperature;

means for bonding the first material and the second material together at approximately the first temperature and the second temperature, respectively; and

wherein:

the first material has a first amount of change in size upon the first material changing from the first temperature to a third temperature;

the second material has a second amount of change in size upon the second material changing from the second temperature to a fourth temperature; and

the first amount of change in size is approximately the same as the second amount of change in size.

12. The means of claim 11, wherein the third temperature is approximately the same as the fourth temperature.

13. The means of claim 12, wherein:

the first material has a first thermal expansion coefficient;

the second material has a second thermal expansion coefficient; and

the first and second thermal expansion coefficients are different.

14. The means for claim 13, wherein the first and second materials are for MEMS devices.

15. The means of claim 12, wherein:

the first material is silicon; and

the second material is glass.

16. The means of claim 15, wherein the glass is Pyrex™.

17. The means of claim 15, wherein the glass is Hoya™ SD2.

18. The means of claim 13, wherein the third and fourth temperatures are approximately equivalent to a pre-bonding temperature.

19. A bonding device comprising:

a first material holder having a first heater; and

a second material holder, having a second heater, proximate to the first material holder; and

wherein:

one holder is moveable relative to the other holder;

the first heater has a first adjustable temperature; and the second heater has a second adjustable temperature.

20. The device of claim 19, wherein:

the first heater may heat a first material in the first holder to a first temperature;

the second heater may heat a second material in the second holder to a second temperature; and

the holders may move toward each other to bond the first material and the second material together.

21. The device of claim 20, further comprising:

an actuator connected to one of the first and second holders; and

a processor connected to the first and second heaters and to the actuator.

22. The device of claim 21 wherein the processor is programmable to bond the two materials resulting in a predetermined amount of stress between the materials at a third temperature.

23. The device of claim 22, wherein:

the first temperature is a bonding temperature of the first material; and

the second temperature is a bonding temperature of the second material.

24. The device of claim 23, wherein the third temperature is a normal ambient temperature of the first and second materials.

25. The device of claim 22, wherein:

ΔT_1 is a difference between the first temperature and the third temperature;

ΔT_2 is a difference between the second temperature and the third temperature;

α_1 is a thermal expansion coefficient for the first material

α_2 is a thermal expansion coefficient for the second material; and

$\alpha_1 \Delta T_1 \approx \alpha_2 \Delta T_2$.

26. The device of claim 25, wherein the two materials are situated in a vacuum environment during bonding.

27. The device of claim 26, wherein the first and second materials are MEMS components.

28. The device of claim 26, wherein:

the first material is silicon; and

the second material is glass.

29. The device of claim 28, wherein the glass is Pyrex™.

30. The device of claim 28, wherein the glass is Hoya™ SD2.

31. A system for bonding comprising:

providing a temperature to each item according to its thermal expansion coefficient to bond the items to each other, such that after bonding and upon return to a pre-bonding temperature, the items change in size relative to each other to result in insignificant stress between the items at the bond; and wherein the items have different coefficients of thermal expansion.

32. The system of claim 31, wherein the items are MEMS components.

33. The system of claim 31, wherein:

the first material is silicon; and

the second material is glass.

34. The system of claim 33, wherein the glass is Pyrex™.

35. The system of claim 33, wherein the glass is Hoya™ SD2.

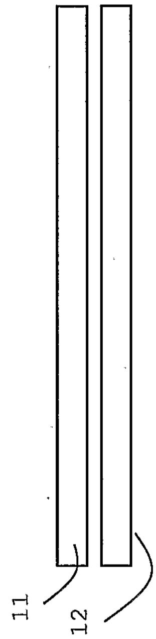


FIGURE 2a

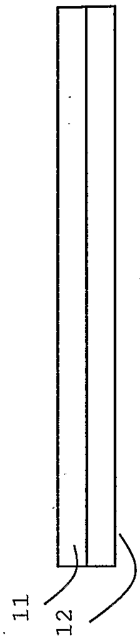


FIGURE 2b

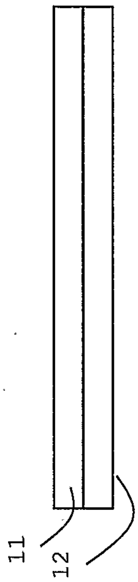


FIGURE 2c

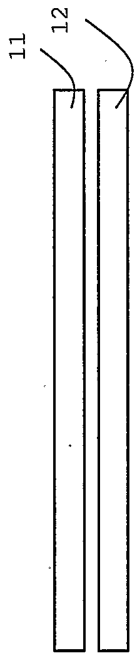


FIGURE 1a

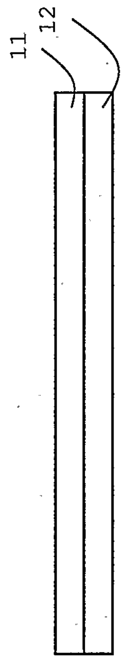


FIGURE 1b

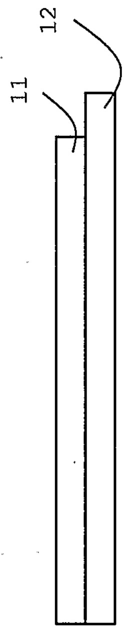


FIGURE 1c

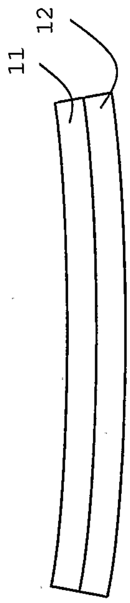
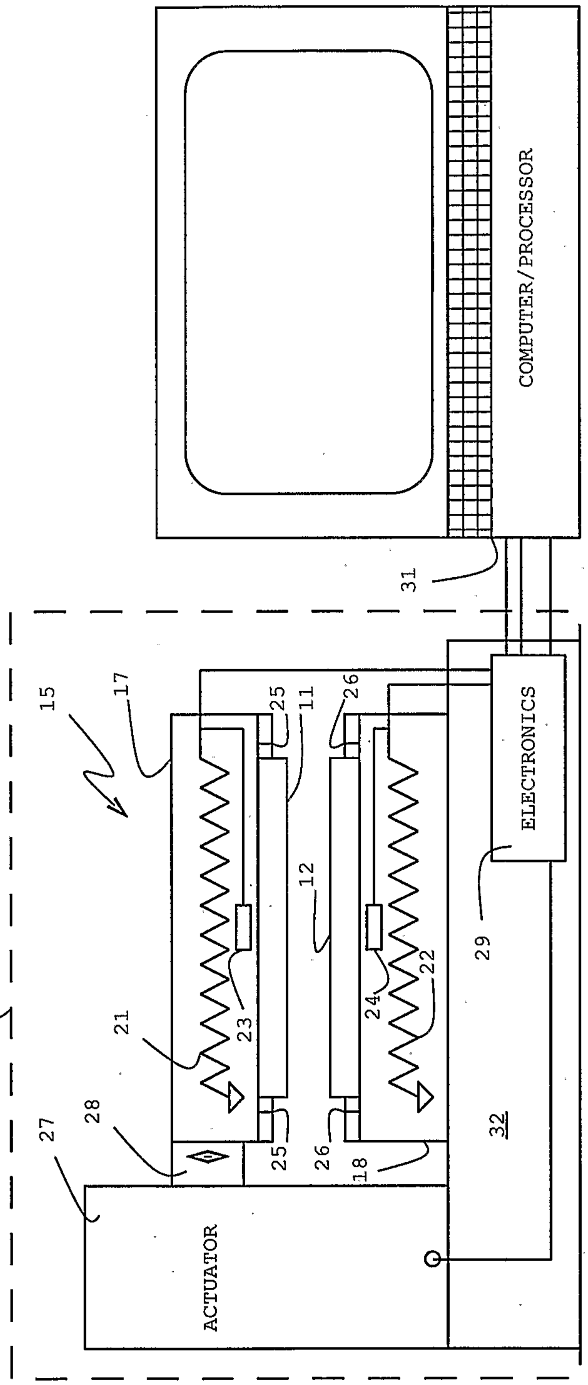


FIGURE 1d


COMPUTER/PROCESSOR
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ACTUATOR
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FIGURE 3