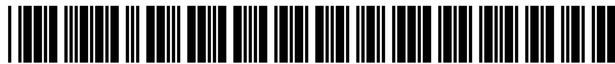

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(54) **METHOD OF BONDING A STACK OF LAYERS BY ELECTROMAGNETIC INDUCTION HEATING**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 376 days.

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(65) **Prior Publication Data**

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(51) **Int. Cl.**[7] **H01L 21/30**; H05B 6/64
(52) **U.S. Cl.** **438/455**; 219/678
(58) **Field of Search** 438/455–459; 219/678

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,334,354 A * 6/1982 Luft et al. 29/840
4,871,412 A * 10/1989 Felix et al. 156/273.9
4,883,215 A * 11/1989 Goesele et al. 438/455
5,273,205 A * 12/1993 Ju et al. 438/455
5,313,034 A * 5/1994 Grimm et al. 219/765
5,338,611 A * 8/1994 Lause et al. 428/412
5,448,041 A * 9/1995 Benoit et al. 219/768
5,479,684 A * 1/1996 Murphy 29/25.35
5,534,097 A * 7/1996 Fasano et al. 156/214
5,707,466 A 1/1998 Atwater et al. 148/525
5,804,801 A * 9/1998 Lauf et al. 219/759
5,851,319 A * 12/1998 Atwater et al. 148/525
5,932,048 A * 8/1999 Furukawa et al. 156/153
6,008,113 A * 12/1999 Ismail et al. 438/615
6,057,212 A * 5/2000 Chan et al. 438/455
6,078,035 A * 6/2000 Chittipeddi et al. 219/759
6,308,406 B1 * 10/2001 Gill et al. 29/849
6,312,548 B1 * 11/2001 Fathi et al. 156/275.1
6,348,679 B1 * 2/2002 Ryan et al. 219/634
6,413,874 B1 * 7/2002 Sato 438/714
6,734,409 B1 * 5/2004 Wang et al. 219/759

OTHER PUBLICATIONS

Stanley Wolf, Silicon Processing For the VLSI 1986, Lattice Press, vol. 1, pp. 57–58.*

* cited by examiner

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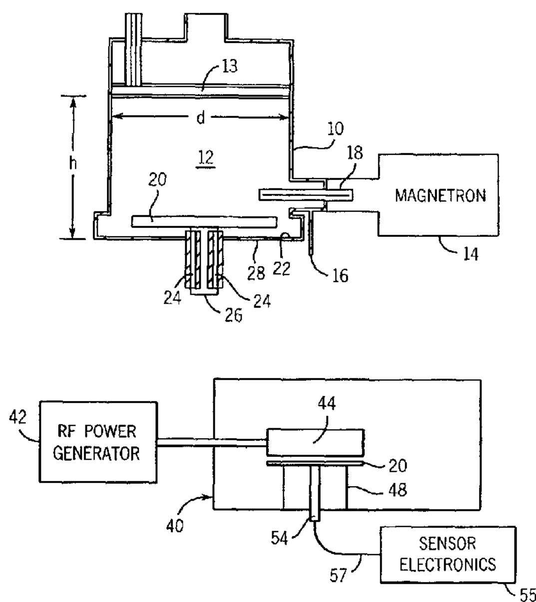
(57) **ABSTRACT**

A method of bonding multiple layers is provided. The method includes the steps of stacking the multiple layers on top of each other and volumetrically heating the stack of multiple layers to a predetermined temperature. It is preferred that the stack is heated by electromagnetic induction.

48 Claims, 1 Drawing Sheet



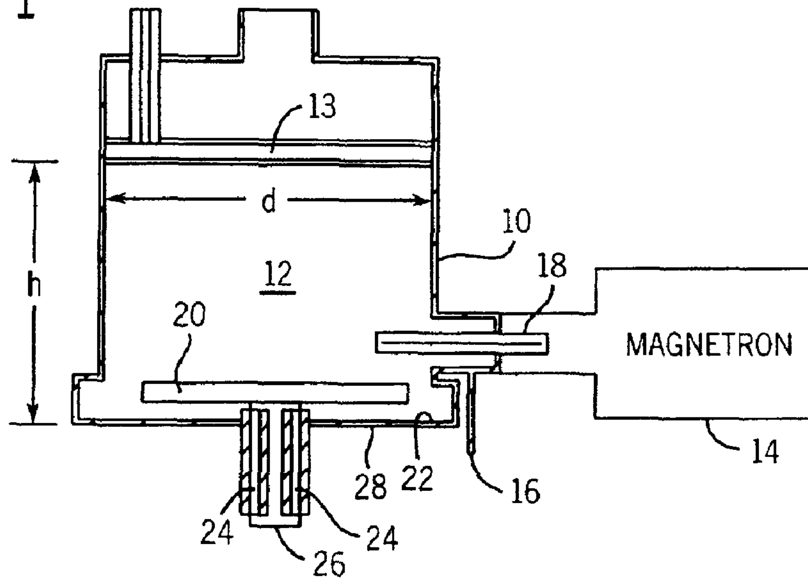


FIG. 1
13
d
h
10
12
18
20
MAGNETRON
28
22
16
14
24
24
26

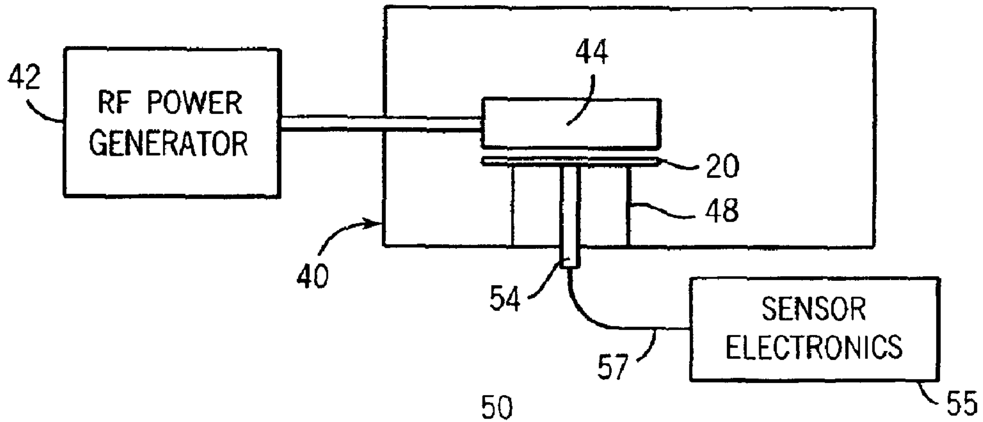
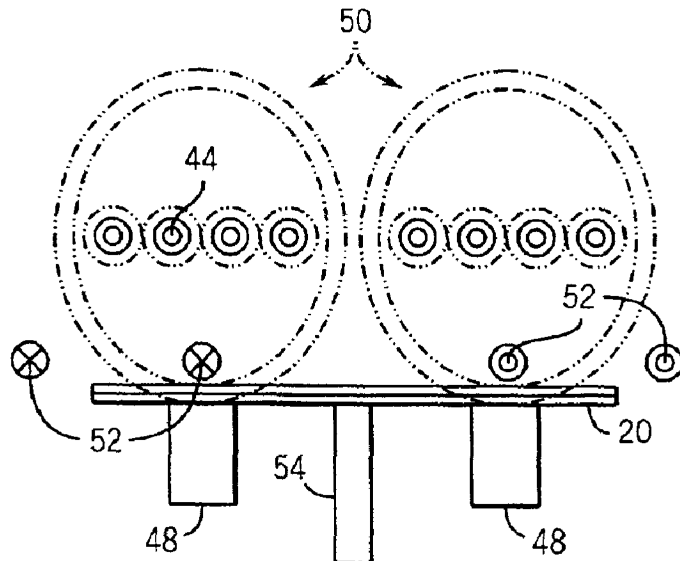


FIG. 2
44
42
RF POWER GENERATOR
20
48
40
54
SENSOR ELECTRONICS
57
55


50
44
FIG. 3
52
52
20
54
48
48

METHOD OF BONDING A STACK OF LAYERS BY ELECTROMAGNETIC INDUCTION HEATING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application Ser. No. 60/297,137, filed Jun. 8, 2001.

REFERENCE TO GOVERNMENT GRANT

This invention was made with United States government support awarded by the US Civilian Research & Development Foundation, No. RE1-2065. The United States has certain rights in this invention.

FIELD OF THE INVENTION

This invention relates generally to the bonding of multiple layers, and in particular, to a method of bonding a stack of multiple layers through electromagnetic induction heating.

BACKGROUND OF THE INVENTION

In the past decade, silicon-silicon bonding has received increasing use in the fabrication of micromechanical structures and power electronics. Silicon-silicon bonding is also a candidate technology for manufacturing silicon-on-insulator (SOI) wafers, which are attractive for high speed digital microelectronics. By way of example, in metal-oxide-semiconductor (MOS) transistors fabricated on SOI wafers, the parasitic capacitance associated with source and drain junctions is minimal.

In the bonding process, the polished surfaces of the silicon wafers to be bonded are pressed together at moderate temperatures to form an initial pre-bond. To complete the bond and achieve full strength, the wafers require baking at approximately 1000° Celsius. Conventionally, this is done in large furnaces, which require long ramp times, consume large amounts of power, and have significant manufacturing footprints. The resultant high thermal budget limits process flexibility, making process integration difficult. In addition, furnaces lack the flexibility to adapt to unconventional bonding requirements such as multi-wafer stacks.

It can be appreciated that silicon bonding through electromagnetic induction heating (EMIH) overcomes many conventional limitations. Heretofore, the use of electromagnetic radiation for wafer bonding has been limited. Since it has been assumed that silicon is transparent to electromagnetic radiation because of its small imaginary dielectric response, intermediate glue layers of metal were used to absorb the radiation. In reality, however, the ohmic response of silicon to an oscillating magnetic flux can be used to directly heat the silicon.

SUMMARY OF THE INVENTION

Therefore, it is a primary object and feature of the present invention to provide a method of bonding a stack of silicon wafers which is simpler and less expensive than prior methods.

It is a further object and feature of the present invention to provide a method of bonding a stack of silicon wafers which consumes less power than prior methods.

It is a still further object and feature of the present invention to provide a method of bonding a stack of silicon wafers which bonds the wafers in a shorter time period than prior methods.

In accordance with the present invention, a method of bonding multiple layers is provided. The method includes the steps of stacking the multiple layers on top of each other and generating an electromagnetic field which intersects the stack of the multiple layers. The electromagnetic field heats the multiple layers to a predetermined temperature.

The method may include the additional step of providing a resonant cavity extending along a longitudinal axis. The cavity has length which is adjustable along the axis. The stack of multiple layers is positioned in the cavity at a predetermined location where the intensity of the electromagnetic field is maximized. The length of the cavity may be adjusted to a user selected length to vary the electromagnetic field.

The step of generating the electromagnetic field may include injecting microwave radiation into the cavity and tuning the microwave radiation to minimize reflections from the cavity. Alternatively, the step of generating the electromagnetic field may include the step of generating a magnetic field which intersects the stack of multiple layers. The magnetic field may be generated by providing a conducting material and passing a current through the conducting material at a predetermined frequency.

It is contemplated to preheat the stack of multiple layers to a coupling temperature so as to initiate the bonding of the multiple layers. It is preferred that the coupling temperature be between 20° and 200° Celsius and the predetermined temperature be between 800° and 1100° Celsius.

The multiple layers may be cleaned prior to stacking the multiple layers to facilitate the bonding of the layers in a stack. The layers are cleaned first in a $NaOH:H_2O_2:H_2O$ (5:1:1) solution at 80° Celsius, followed by a $H_2SO_4:H_2O$ (5:1) solution at 80° Celsius. In addition, the step of cleaning the multiple layers may also include the additional steps of dipping the layers in dilute (100:1) HF to remove any residual oxide layer; rinsing the layers in deionized water; and spinning the layers completely dry to minimize the amount of residual moisture thereon.

In accordance with a further aspect of the present invention, a method of bonding multiple layers is provided. The method includes the steps of stacking the multiple layers on top of each other and volumetrically heating the stack of multiple layers to a predetermined temperature.

A resonant cavity extending along a longitudinal axis is provided and an electromagnetic field is generated therein. The cavity has length which is adjustable along the axis to vary the electromagnetic field. The stack of multiple layers is positioned in the cavity at a predetermined location where the intensity of the electromagnetic field is maximized.

The electromagnetic field may be generated by injecting microwave radiation into the cavity and by tuning the microwave radiation to minimize reflections from the cavity. Alternatively, the electromagnetic field may be generated by generating a magnetic field which intersects the stack of multiple layers. The magnetic field may be generated by providing a conducting material and passing a current through the conducting material at a predetermined frequency.

It is contemplated to preheat the stack of multiple layers to a coupling temperature so as to initiate the bonding of the multiple layers. It is preferred that the coupling temperature be between 20° and 200° Celsius and the predetermined temperature be between 800° and 1100° Celsius.

The multiple layers may be cleaned prior to stacking the multiple layers to facilitate the bonding of the layers in a stack. The layers are cleaned first in a $NaOH:H_2O_2:H_2O$

(5:1:1) solution at 80° Celsius, followed by a H_2SO_4:H_2O (5:1) solution at 80° Celsius. In addition, the step of cleaning the multiple layers may also include the additional steps dipping in dilute (100:1) HF (hydrogen floride) to remove any residual oxide layer; rinsing the layers in deionized water; and spinning the layers completely dry to minimize the amount of residual moisture thereon.

In accordance with a still further aspect of the present invention, a method of bonding multiple layers is provided. The layers are cleaned in a NaOH:H_2O_2:H_2O (5:1:1) solution at 80° Celsius, followed by a H_2SO_4:H_2O (5:1) solution at 80° Celsius. The cleaned multiple layers are brought into contact together to form a stack that is volumetrically heated to a predetermined temperature.

The step of cleaning the multiple layers may also include the additional steps dipping in dilute (100:1) HF to remove any residual oxide layer; rinsing the layers in deionized water; and spinning the layers completely dry to minimize the amount of residual moisture thereon.

A generally cylindrical resonant cavity extending along a longitudinal axis is provided and an electromagnetic field is generated therein. The cavity has length which is adjustable along the axis to vary the electromagnetic field. The stack of multiple layers is positioned in the cavity at a predetermined location where the intensity of the electromagnetic field is maximized.

The electromagnetic field may be generated by injecting microwave radiation into the cavity and by tuning the microwave radiation to minimize reflections from the cavity. Alternatively, the electromagnetic field may be generated by generating a magnetic field which intersects the stack of multiple layers. The magnetic field may be generated by providing a coil winding and passing a current through the coil winding at a predetermined frequency.

It is contemplated to preheat the stack of multiple layers to a coupling temperature so as to initiate the bonding of the multiple layers. It is preferred that the coupling temperature be between 20° and 200° Celsius and the predetermined temperature be between 800° and 1100° Celsius.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings furnished herewith illustrate a preferred construction of the present invention in which the above advantages and features are clearly disclosed as well as others which will be readily understood from the following description of the illustrated embodiment.

In the drawings:

FIG. **1** is a schematic view of a structure for the electromagnetic induction heating of a plurality of silicon wafers in accordance with the method of the present invention;

FIG. **2** is a schematic view of an alternate structure for the electromagnetic induction heating of a plurality of silicon wafers in accordance with the method of the present invention; and

FIG. **3** is a second, schematic view of the alternate structure of FIG. **2**.

DETAILED DESCRIPTION OF THE DRAWINGS

It can be appreciated that electromagnetic induction heating (EMIH) is a unique application of Faraday's and Ampere's laws. When a silicon wafer is exposed to oscillating magnetic fields, currents—more specifically electrons and holes—are induced to flow within the wafer (Faraday's law). These electrons, through collisions with the lattice, give up their energy by heating the wafer.

Predicting the magnitude of these induced currents, however, requires a more detailed analysis of Faraday's and Ampere's laws. The currents induced in highly conducting materials, e.g. copper, re-induce a magnetic field that partially or completely interferes destructively with the incident field. This is commonly known as shielding or skin-depth. Conversely, the lack of free carriers in insulating materials, e.g. quartz, precludes any flow of current and allows the incident field to penetrate through the material. Semiconductors fall in between these two extremes and therefore have the potential for significant field penetration that induces substantial currents throughout the volume of the wafer. This enables the possibility for substantial and volumetric heating, rather than just surface heating. This can be illustrated best by a self-consistent solution of Ampere's and Faraday's laws that obtains a first order description of induced current density and the subsequent power absorbed:

$$P_{ABS} = \frac{\pi a^2 t_w^3/(\delta^4 \sigma)}{1 + (t_w/\delta)^4} H_0^2,\ \delta = \sqrt{2/\omega\mu\sigma} \tag{1}$$

wherein: σ is conductivity; t_w is thickness; δ is skin depth; ω is frequency; μ is permeability; "a" is radius; and H_0 is the incident magnetic field. It is inferable from Equation (1) that the absorbed power increases with conductivity, σ, until a peak absorption point is reached at which point the power decreases and asymptotes to zero.

The strong dependence of power absorption on conductivity adds an elusive element to the heating of silicon because of the non-linear relationship between temperature and conductivity in a silicon wafer. As is known, conductivity is the product of mobility and carrier density. However, both these terms, mobility and carrier density, have opposing relationships with respect to temperature. Mobility decreases with temperature due to an increased collision frequency that impedes the flow of carriers. Carrier density increases with temperature as the increased thermal energy moves more carriers from the valence band into the conduction band; thereby increasing the intrinsic carrier concentration.

It can be appreciated that conductivity initially decreases with temperature—as collisions impede carrier mobility—until the temperature exceeds ~100° Celsius. At such point, the increase in intrinsic carriers overcomes the loss in mobility and conductivity increases monotonically with temperature. As a result, a conductivity valley exists just above room temperature (50–125° Celsius). This creates, due to the strong dependence of power absorption on conductivity, the possibility of an absorption valley which prevents the wafer from heating beyond ~100° Celsius. Once beyond this point, conductivity increases with temperature and power absorption increases with conductivity. This creates a runaway heating effect that results in extremely rapid temperature ramp rates. Further, above ~500° Celsius, the intrinsic carrier concentration becomes much greater than the background doping; consequently, the intrinsic carriers, not the specific wafer doping, dominate conductivity. Consequently, above 500° Celsius wafer heating becomes independent of the initial substrate doping, and silicon wafers of various room temperature conductivities heat in an identical fashion.

Referring to FIG. **1**, a cylindrical resonant chamber for electromagnetic induction heating a plurality of layers such as silicon wafers is generally designated by the reference numeral **10**. Resonant chamber **10** defines a cavity **12** having a predetermined diameter d and an adjustable height h.

Height h of cavity **12** is adjusted by moving adjustable top **13** which, in turn, allows a user to tune in specific modes, for reasons hereinafter described.

Resonant chamber **10** is operatively connected to magnetron **14** by a waveguide **16**. Magnetron **14** converts electrical energy to microwave radiation such that magnetron **14** may provide microwaves to cavity **12** within resonant chamber **10** through waveguide **16**. As is known, magnetron **14** is capable of generating microwaves having frequencies between 100 MHz and 10 GHz. However, it is contemplated as being within the scope of the present invention to replace magnetron **14** with an alternate microwave generator in order to provide microwaves having frequencies of up to 30 GHz. Radial tuner **18** is positioned in the interior of waveguide **16** to minimize reflected power.

A plurality of layers such as silicon wafers **20** is positioned on hollow quartz cylinders **24** within cavity **12** of resonant chamber **10** adjacent cavity bottom **22** thereof. Silicon wafers **20** are positioned just above cavity bottom **22** to ensure that the silicon wafers **20** are in a magnetic field maximum. Since the electromagnetic energy absorbed by silicon wafers **20** is directly proportional to the magnetic field intensity, the uniformity of the magnetic field pattern in cavity **12** for the various modes in the plane of silicon wafers **20** can have a strong influence on the uniformity of the heating of silicon wafers **20**. As such, adjustable top **13** of resonant chamber **10** is positioned by a user to tune in specific modes.

In order to heat silicon wafers **20** utilizing EMIH, intense electromagnetic fields must be used to induce currents to flow through silicon wafer **20**. Magnetron **14** provides cavity **12** with microwaves, as heretofore described, such that highly energetic electrons collide with the lattice of the silicon, transferring energy to the lattice in the form of heat. As the temperature of the silicon wafers **20** rises, additional electrons move into the conduction band and are available to flow as current, thereby increasing the power absorbed by silicon wafers. This process continues until radiation losses equal the power absorbed, forcing a steady state operating point. As described, silicon wafers **20** can be rapidly ramped to temperatures in the range of 800° to 1100° Celsius, and preferably above 1000° Celsius, so as to bond the plurality of silicon wafers **20** together. It is contemplated to create the bond between the silicon wafers **20**, silicon wafers **20** are ramped to 1000° C. at a rate of 125° C./sec, soaked at 1000° Celsius for 5 minutes, and cooled to room temperature in ≈5 seconds.

It can be appreciated that temperature measurement in the presence of intense electromagnetic fields is difficult under the best circumstances. In order to obtain such temperature measurement, an optical pyrometer or light-pipe **26**, calibrated to the specific emissivity of silicon in the temperature range of interest (800–1100° Celsius), is fed through the bottom **28** of resonant chamber **10**. Light pipe **26** allows the temperature to be accurately measured without perturbing the field patterns. In addition, light-pipe **26** may be used to obtain localized spatial measurements.

Referring to FIGS. **2**–**3**, an alternate structure for electromagnetic induction heating a plurality of silicon wafers is generally designated by the reference numeral **40**. Structure **40** includes a radio frequency power generator **42** operatively connected to a radio frequency antenna **44**. In the preferred embodiment, radio frequency antenna **44** takes the form a copper coil winding.

A plurality of layers such as silicon wafers **20** are stacked upon each other and are positioned on a plurality of ceramic support rods **48** just below (e.g. 2.5 centimeters) radio frequency antenna **44**. Ceramic support rods **48** may be heated in any conventional manner to a user desired temperature between 20° and 200° Celsius, and preferably 150° Celsius, in order to preheat silicon wafers **20** to such point as to initiate coupling of silicon wafers **20** to each other.

In operation, frequency power generator **42** provides current at a frequency less than 300 MHz through radio frequency antenna **44** to induce magnetic field **50** and electric field **52**. Fields **50** and **52** induce highly energetic electrons collide with the lattice of the silicon, transferring energy to the lattice in the form of heat. As the temperature of the silicon wafers **20** rises, additional electrons move into the conduction band and are available to flow as current, thereby increasing the power absorbed by silicon wafers **20**. This process continues until radiation losses equal the power absorbed, forcing a steady state operating point. As described, silicon wafers **20** can be rapidly ramped to temperatures in the range of 800° to 1100° Celsius, and preferably above 1000° Celsius, so as to bond the plurality of silicon wafers **20** together. As heretofore described, to create the bond between the plurality of silicon wafers **20**, silicon wafers **20** are ramped to 1000° Celsius at a rate of 125° C./sec, soaked at 1000° Celsius for 5 minutes, and cooled to room temperature in ≈5 seconds.

In order to obtain such temperature measurement, an optical pyrometer or light pipe **54**, calibrated to the specific emissivity of silicon in the temperature range of interest (800–1100° Celsius), is positioned adjacent silicon wafers **20**. Light pipe is operatively connected to various sensor electronics **55** by optical fiber **57**. Sensor electronics **55** process the signals received from light pipe **54** such that light pipe **54** may be used to the temperature to be accurately measure the temperature of the silicon wafers **20** without perturbing the field patterns. In addition, light pipe **54** may be used to obtain localized spatial measurements.

Surface preparation is an important step in conventional wafer bonding, as well as, in EMIH bonding. Poor surface preparation can result in voids, particularly when rapid temperature ramps are used. During the heating process, adsorbed water trapped between the wafer surfaces quickly vaporizes and expands, increasing local pressures along the bond interface. This pressure can force the surfaces of silicon wafers **20** apart, creating voids in an otherwise uniform bond. Furthermore, the oxygen present in the water may react locally with the silicon surface to form silicon dioxide, making uneven the surface over which the bond is formed. In extreme cases, silicon wafers **20** may delaminate during the temperature ramp.

In order to minimize the possibility of void formation along the bond interfaces of the plurality of silicon wafers **20**, silicon wafers **20** may be cleaned prior to EMIH. The silicon wafers **20** are first cleaned in a $NaOH:H_2O_2:H_2O$ (5:1:1) solution at 80° Celsius, followed by a $H_2SO_4:H_2O$ (5:1) solution at 80° Celsius, and finally dipped in dilute (100:1) HF to remove any residual oxide layer. Silicon wafers may then be rinsed in deionized water and spun completely dry to minimize the amount of residual moisture on the surfaces of the silicon wafers **20**. Once dry, silicon wafers **20** are immediately pressed together, and thereafter, bonded together as heretofore described.

It is contemplated to clean the silicon wafers **20** in other manners including, but are not limited to, oxygen plasma or hydrogen plasma treatments followed by a vigorous rinse in deionized water. It is intended for the cleaning of silicon wafers **20** to remove particulates and contaminants from the

surface of silicon wafers **20** and to condition such surfaces for optimal bonding prior to the stacking the silicon wafers **20**.

While the method of the present invention has been described in connection with silicon-silicon bonding, it can be appreciated that other types of bonding, such as silicon-on-insulator bonding, are contemplated without deviating from the scope of the present invention. Further, the bonding of materials such as Germanium and Si—Ge hybrid materials are contemplated as being within the scope of the present invention. As such, it can be appreciated that various modes of carrying out the invention are contemplated as being within the scope of the following claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention.

We claim:

1. A method of bonding multiple layers, the method comprising the steps of:

stacking the multiple layers on top of each other; and

generating an electromagnetic field which intersects and volumetrically heats the multiple layers to a predetermined temperature.

2. The method of claim **1** comprising the additional steps of:

providing a resonant cavity extending along a longitudinal axis, the cavity having length which is adjustable along the axis; and

positioning the stack of multiple layers in the cavity.

3. The method of claim **2** wherein the stack of multiple layers are positioned within the cavity at a predetermined location wherein the intensity of the electromagnetic field is maximized.

4. The method of claim **2** comprising the additional step of adjusting the length of cavity to a user selected length to vary the electromagnetic field.

5. The method of claim **2** wherein the step of generating electromagnetic fields includes injecting microwave radiation into the cavity.

6. The method of claim **5** comprising the additional step of tuning the microwave radiation to minimize reflections from the cavity.

7. The method of claim **1** wherein the step of generating the electromagnetic field includes the step of generating a magnetic field which intersects the stack of multiple layers.

8. The method of claim **7** wherein the step of generating a magnetic field includes the steps of providing a conducting material and passing a current at a predetermined frequency through the conducting material.

9. The method of claim **7** wherein the predetermined frequency is less than 300 MHz.

10. The method of claim **1** comprising the additional step of preheating the stack of multiple layers to a coupling temperature so as to initiate bonding of the multiple layers.

11. The method of claim **10** wherein the coupling temperature is between 20° and 200° Celsius.

12. The method of claim **1** wherein the predetermined temperature is between 800° and 1100° Celsius.

13. The method of claim **1** further comprising the additional step of cleaning the multiple layers prior to stacking the multiple layers.

14. The method of claim **13** comprising the additional step of bringing the multiple layers into contact after the step of stacking the multiple layers.

15. The method of claim **13** wherein the step of cleaning the multiple layers includes the steps:

depositing each of the multiple layers in a $NaOH:H_2O_2:H_2O$ (5:1:1) solution at 80° Celsius; and

depositing each of the multiple layers in a $H_2SO_4:H_2O$ (5:1) solution at 80° Celsius.

16. The method of claim **13** wherein the step of cleaning the multiple layers includes the additional steps:

dipping each of the multiple layers in dilute (100:1) HF;

rinsing each of the multiple layers in deionized water; and

spinning the multiple layers completely dry.

17. A method of bonding multiple layers, the method comprising the steps of:

stacking the multiple layers on top of each other; and

generating an electromagnetic field which intersects the stack of the multiple layers to volumetrically heat the stack of multiple layers to a predetermined temperature.

18. The method of claim **17** comprising the additional steps of:

providing a resonant cavity extending along a longitudinal axis, the cavity having length which is adjustable along the axis; and

positioning the stack of multiple layers in the cavity.

19. The method of claim **18** wherein the stack of multiple layers are positioned within the cavity at a predetermined location wherein the intensity of the electromagnetic field is maximized.

20. The method of claim **18** comprising the additional step of adjusting the length of cavity to a user selected length to vary the electromagnetic field.

21. The method of claim **18** wherein the step of generating electromagnetic fields includes injecting microwave radiation into the cavity.

22. The method of claim **21** comprising the additional step of tuning the microwave radiation to minimize reflections from the cavity.

23. The method of claim **17** comprising the additional step of preheating the stack of multiple layers to a coupling temperature so as to initiate bonding of the multiple layers.

24. The method of claim **23** wherein the coupling temperature is between 20° and 200° Celsius.

25. The method of claim **17** wherein the predetermined temperature is between 800° and 1100° Celsius.

26. The method of claim **17** further comprising the additional step of cleaning the multiple layers prior to stacking the multiple layers.

27. The method of claim **26** wherein the step of cleaning the multiple layers includes the steps:

depositing each of the multiple layers in a $NaOH:H_2O_2:H_2O$ (5:1:1) solution at 80° Celsius; and

depositing each of the multiple layers in a $H_2SO_4:H_2O$ (5:1) solution at 80° Celsius.

28. The method of claim **27** wherein the step of cleaning the multiple layers includes the additional steps:

dipping each of the multiple layers in dilute (100:1) HF;

rinsing each of the multiple layers in deionized water; and

spinning the multiple layers completely dry.

29. The method of claim **17** comprising the additional step of bringing the multiple layers into contact after the step of stacking the multiple layers.

30. The method of claim **17** wherein the stack of multiple layers is heated by electromagnetic induction.

31. A method of bonding multiple layers, the method comprising the steps of:

depositing each of the multiple layers in a $NaOH:H_2O_2:H_2O$ (5:1:1) solution at 80° Celsius;

depositing each of the multiple layers in a $H_2SO_4:H_2O$ (5:1) solution at 80° Celsius;

pressing the multiple layers together to form a stack; and

volumetrically heating the stack to a predetermined temperature.

32. The method of claim **31** wherein the step of heating the stack includes the step of generating an electromagnetic field which intersects the stack.

33. The method of claim **32** comprising the additional steps of:

providing a resonant cavity extending along a longitudinal axis, the cavity having length which is adjustable along the axis; and

positioning the stack in the cavity.

34. The method of claim **33** wherein the stack is positioned within the cavity at a predetermined location wherein the intensity of the electromagnetic field is maximized.

35. The method of claim **33** comprising the additional step of adjusting the length of cavity to a user selected length to vary the electromagnetic field.

36. The method of claim **33** wherein the step of generating the electromagnetic field includes injecting microwave radiation into the cavity.

37. The method of claim **36** comprising the additional step of tuning the microwave radiation to minimize reflections from the cavity.

38. The method of claim **31** wherein the step of heating the stack includes the step of generating a magnetic field which intersects the stack of multiple layers.

39. The method of claim **38** wherein the step of generating the magnetic field includes the steps of providing a conducting material and passing a current at a predetermined frequency through the conducting material.

40. The method of claim **38** wherein the predetermined frequency is less than 300 MHz.

41. The method of claim **31** comprising the additional step of preheating the stack to a coupling temperature so as to initiate bonding of the multiple layers.

42. The method of claim **41** wherein the coupling temperature is between 20° and 200° Celsius.

43. The method of claim **31** wherein the predetermined temperature is between 800° and 1100° Celsius.

44. The method of claim **31** wherein the stack is heated by electromagnetic induction.

45. The method of claim **31** further comprising the additional step of cleaning the multiple layers by:

dipping each of the multiple layers in dilute (100:1) HF;

rinsing each of the multiple layers in deionized water; and

spinning the multiple layers completely dry.

46. A method of bonding multiple layers, the method comprising the steps of:

stacking the multiple layers on top of each other; and

generating a magnetic field which intersects the stack of multiple layers to volumetrically heat the stack of multiple layers to a predetermined temperature.

47. The method of claim **46** wherein the step of generating the magnetic field includes the steps of providing a conducting material and passing a current at a predetermined frequency through the conducting material.

48. The method of claim **47** wherein the wherein the predetermined frequency is less than 300 MHz.

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