

A METHOD OF BONDING TWO WAFERS MADE OUT OF MATERIALS
SELECTED FROM SEMICONDUCTOR MATERIALS

The present invention relates to a method of bonding
two wafers made out of materials selected from
5 semiconductor materials, said method making use of plasma
activation of the surface of at least one of the two
layers that are to be bonded together.

BACKGROUND OF THE INVENTION

Methods of this type are already known.

10 The term "bonding" is used herein to mean bonding by
molecular bonding during which two perfectly plane
surfaces are bonded together without applying any
adhesive - and this being possible at ambient
temperature.

15 The quality of the bond is characterized in
particular by its bonding energy, which represents the
connection force between the two bonded-together wafers.

In order to consolidate bonding by molecular bonding
between two wafers, the bonded-together wafers are
20 subjected to heat treatment.

Such heat treatment enables the bonding energy of
the two wafers to be raised to a value of at least about
500 millijoules per square meter (mJ/m^2), where this
corresponds to the values that are typically desired.

25 In conventional manner, such heat treatment is
generally carried out at a temperature of at least about
900°C (which in the context of the present specification
defines the "high temperature" domain). When bonding
between a wafer made of Si and a wafer made of Si or of
30 SiO_2 , the bonding energy is maximized when heat treatment
is carried out at temperatures of the order of 1100°C to
1200°C.

"Plasma activation" of a surface for bonding is
defined as exposing said surface to a plasma (which can
35 be carried out in particular under a vacuum or at
atmospheric pressure) prior to putting the surfaces for
bonding together into contact.

More precisely, in prior art activation techniques, the surface of a wafer for activation is exposed to a plasma during an exposure step in which the exposure parameters are controlled so that each is set at a given
5 respective value, which values remain unchanged during plasma activation.

First order "exposure parameters" are as follows:

- power density; this is the density of the power feeding the plasma, which represents a power density per
10 unit area in watts per square centimeter (W/cm^2), and is sometimes also referred to in the present specification by the term "power", for simplicity;
- pressure (pressure in the enclosure containing the plasma); and
- 15 • the nature and the flow rate of the gas fed into said enclosure.

Such activation serves in particular to perform bonding by molecular bonding, obtaining high bonding energies without requiring any recourse to heat treatment
20 that would necessarily need to be carried out at high temperatures.

Plasma activation thus makes it possible to obtain high bonding energies between two wafers, at least one of which is activated prior to bonding, and after applying
25 heat treatment over relatively short durations (e.g. about 2 hours (h)), and at temperatures that are relatively low (e.g. about 600°C , or less).

Such activation is thus advantageous for stabilizing a structure comprising two bonded-together wafers, when
30 it is desired to avoid subjecting the structure to temperatures that are too high (as applies in particular to heterostructures, defined as being structures comprising layers made of materials having coefficients of thermal expansion that are significantly different).

35 Such activation can also be advantageous for obtaining high bonding forces at a given temperature.

Such activation is thus advantageous for making multilayer structures involving the bonding together of two wafers, for example.

Transfer methods (in particular methods of the Smart Cut™ type as described in general terms in the work "Silicon-on-insulator technology: materials to VLSI", 2nd edition (Jean-Pierre Colinge)) constitute one example of an application that can benefit from plasma activation to enhance bonding.

OBJECTS AND SUMMARY OF THE INVENTION

Embodiments of the invention seek to improve prior art bonding techniques that implement plasma activation.

In particular, embodiments of the invention seek to increase the bonding energy obtained after plasma activation.

Embodiments of the invention also seek to make it possible to obtain a high level of bonding energy, even when only one of the two surfaces for bonding together has been plasma-activated prior to bonding.

In accordance with a first aspect, the invention provides a method of bonding together two wafers made of materials selected from semiconductor materials, said method implementing plasma activation of the surface of at least one of the two wafers to be bonded together, and comprising, during plasma activation, controlling the activation parameters to modify the kinetic energy of the species contained in the plasma in order to create a disturbed region of controlled thickness in the thickness of a surface region of the wafer whose surface is being activated.

Preferred but non-limiting features of the method according to embodiments of the invention are as follows:

- said control of the activation parameters also serves to control the maximum depth of said disturbed region in said wafer whose surface is being activated;
- said control of the activation parameters comprises controlled variation of said parameters;

- said disturbed region extends in the thickness of said wafer whose surface is being activated between a depth of 10 angstroms (Å) and a depth of 250 Å;
- said species are the ions of the plasma;
- 5 · said control seeks to obtain kinetic energy for said species contained in the plasma at a level lying in the range 10 electron volts (eV) to 2 kilo electron volts (keV);
- said control of the activation parameters
- 10 comprises controlling kinetic energy by controlling the power density fed to an electrode connected to the wafer whose surface is to be activated;
- said power density is controlled in such a manner as to achieve controlled variation in the density of the
- 15 power generating the plasma;
- said power density is caused to vary by initially applying "high" power, and subsequently applying "low" power, that is lower than the high power;
- variation between high power and low power is
- 20 performed in power steps, one power step corresponding to high power, and another power step corresponding to low power;
- the step corresponding to high power and the step corresponding to low power are each carried out for a
- 25 duration lying in the range 5 seconds (s) to 60 s;
- the step corresponding to high power and the step corresponding to low power are each carried out for a duration lying in the range 10 s to 30 s;
- variation between high power and low power is
- 30 performed by causing the power to decrease in continuous manner from the high power down to the low power;
- the high power has a value lying in the range 1.5 W/cm² to 15 W/cm² of the area to be activated, and the low power has a value lying in the range 0.15 W/cm² to
- 35 1.5 W/cm² of the area to be activated;

- the high power has a value of 3 W/cm² of the area to be activated and the low power has a value of 0.8 W/cm² of the area to be activated;

- the surface of the wafer to be activated is a disk
5 having a diameter of 200 millimeters (mm), the high power has a value of 1000 watts (W), and the low power has a value of 250 W;

- the surface of the wafer to be activated is a disk
10 having a diameter of 300 mm, the high power has a value of 2000 W, and the low power has a value of 500 W;

- the plasma is generated by equipment of the reactive ion etching (RIE) type having a single radiofrequency (RF) generator feeding the electrode supporting the wafer to be activated via capacitive
15 coupling;

- said variation is performed over a time interval of duration lying in the range 10 s to 2 minutes (min);

- said electrode connected to the wafer whose surface is to be activated is used solely for controlling
20 the kinetic energy of the plasma species;

- said electrode connected to the wafer whose surface is to be activated is used both for controlling the kinetic energy of the plasma species, and for exciting the plasma;

- said control of the activation parameters
25 comprises controlling the kinetic energy by controlling the composition of the gas in which the plasma is created;

- said control of gas composition is performed to
30 obtain controlled variation in the nature of the gas used for generating the plasma;

- said variation consists in treating the surface to be activated with a plasma obtained from a first gas, and subsequently with a plasma obtained from a second gas;

- said first gas is made up of one or more species
35 that is/are lighter in weight than said second gas;

- said first gas is helium and said second gas is oxygen or argon, or said first gas is oxygen and said second gas is argon;

- the first and/or second gas is/are a gas mixture, e.g. a mixture between a species that is to be ionized (Ar or O₂, for example) and a species that is to remain neutral (non-ionized), but that serves to dilute and determine the quantity of the ionized species (the non-ionized species may be constituted by helium, for example);

- said control of the activation parameters comprises controlling kinetic energy by controlling the pressure in the plasma;

- said control of pressure is implemented to obtain controlled variation in pressure;

- said controlled variation in pressure consists in controlling the pressure to occupy a "low" level initially during activation, and then subsequently a "high" level that is greater than said low level;

- said control of the activation parameters is implemented in order to create a single disturbed region in the thickness of said surface region of the wafer whose surface is being activated;

- said control of the activation parameters is implemented in order to create a plurality of disturbed regions in the thickness of said surface region of the wafer whose surface is being activated, each of said disturbed regions extending over a respective depth in the thickness of said wafer; and

- in order to perform said bonding, the surface of only one of the two wafers that are to be bonded together is subjected to plasma activation.

In accordance with a second aspect, the invention provides a method of transferring a thin layer of semiconductor material from a top wafer forming a donor substrate to a base wafer forming a receiver substrate, the method implementing bonding according the first aspect

in order to bond a surface

of said donor substrate to a surface of said receiver substrate.

Preferred but non-limiting features of this method are as follows:

- said transfer method is implemented using the Smart CutTM method implementing weakening implantation prior to bonding in order to create a zone of weakness in the thickness of the donor substrate, followed by detachment at said zone of weakness after bonding; and
- after implantation and prior to bonding, the oxidized surface of said donor substrate is subjected to plasma activation.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features, objects, and advantages of the invention appear more clearly on reading the following description made with reference to the accompanying drawings, in which:

- Figure 1 is a diagram of a distribution of disturbances/disorders that can be obtained in the context of the invention in the thickness of a plasma-activated wafer;

- Figure 2 is a graph illustrating the influence of the power applied for generating the plasma used to activate the surface of a wafer of semiconductor material (in this case surface-oxidized Si) over the thickness of the disturbed zone that is obtained under the surface of said wafer as a result of the activation;

- Figure 3 is a graph showing various possible changes in the level of power applied to generate the plasma used for activating the surface of a semiconductor material wafer, plotted as a function of time. In this graph, the two curves plotted in dashed lines correspond to the prior art (power at a single unchanging value throughout the activation), and the three curves plotted in solid lines correspond to three variant implementations of the invention; and

Figure 4 is a graph illustrating the bonding energy obtained between an Si wafer and a surface-oxidized Si wafer that has been plasma-activated prior to bonding, for four different activation conditions.

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MORE DETAILED DESCRIPTION

Context of the invention

The invention applies to bonding together two wafers of semiconductor material. Each of the materials may be Si, or some other semiconductor material.

The surfaces for bonding together of the two wafers may also be oxidized prior to activation - and more precisely one or the other of the surfaces for bonding together may be oxidized, or both of them may be oxidized.

As explained below, activation can be implemented on both of the surfaces for bonding together, or on only one of them. An advantage of the invention is to be able to activate only one of the two surfaces for bonding together, while nevertheless obtaining sufficiently high bonding energy after they have been bonded together.

It is also specified that the invention makes it possible to obtain bonding in the context of a method of transferring a thin layer of semiconductor material constituting a top wafer forming a donor substrate onto a base wafer forming a receiver substrate. The term "thin layer" is used to mean a layer that is a few tens to a few hundreds of angstroms thick.

In this application to transfer methods, bonding is implemented after activation between a surface of said donor substrate and a surface of said receiver substrate.

Said transfer method can be implemented in particular using the Smart CutTM method in which weakening implantation is performed prior to bonding so as to create a zone of weakness in the thickness of the donor substrate, with detachment being performed in said zone of weakness after bonding.

By way of example, it is specified that prior to bonding, plasma activation can be implemented on the oxidized surface of said donor substrate after it has been implanted.

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Main characteristics of the invention

The invention differs from known methods in which activation is performed in a single step during which the activation parameters are unchanging and do not vary.

10 In the invention, at least one wafer surface for bonding is subjected to plasma activation while controlling the activation parameters for the purpose of modifying the kinetic energy of the species contained in the plasma so as to create a disturbed region of
15 controlled depth in the thickness of a surface region of the wafer whose surface is being activated.

In other words, by controlling the activation parameters, it is possible to obtain a disturbed region in the thickness of each activated surface and that
20 extends into the activated wafer down to a controlled depth as desired.

In addition, controlling the activation parameters also makes it possible to control the thickness of said disturbed region.

25 In practice, it can be desired to constitute a disturbed region that is "buried" in the thickness of the activated wafer, or else a disturbed region that is flush with the surface.

In any event, the invention makes it possible to
30 control the thickness and the depth of the disturbed region that is created (i.e. to control its "maximum" depth and its "minimum" depth in the thickness of the activated wafer).

In this respect, it is specified that it is
35 preferable to perform activation in such a manner as to obtain for the species contained in the plasma:

- during an initial period of the activation, a maximum level of kinetic energy for the activation; and
- subsequently, during a second period of the activation, a level of kinetic energy that is lower.

5 This makes it possible, within the thickness of the wafer being subjected to the activation, to generate:

- during the initial period of the activation, disturbances/disorders (that can be written D) that are large and that are buried around a depth P1 in the wafer;
- 10 and

- during the second period of the activation, disturbances/disorders (that can be written d) that are smaller, and that are buried at a depth P2 that is shallower than the depth P1.

15 This activation control sequence serves to maximize the thickness of the disturbed region, and also to maximize its maximum depth.

It appears that this disturbed region acts as a "reservoir" suitable for receiving the gases and other
20 elements present on the surface that is to be bonded. By attracting and trapping said gases and other elements, the disturbed region thus appears to enhance bonding.

It is thought that the disturbances/disorders D are suitable for being "fed" with gas and other elements for
25 trapping by the disturbances/disorders d that are interposed between the disturbances/disorders D and the surface to be activated - with the disturbances/disorders D and d forming a kind of trapping lattice extending in the depth of the wafer (see Figure 1 which shows a
30 distribution obtained in the thickness of a plasma-activated wafer).

The term "disturbed region" is used in this specification to mean a region that is modified by being
exposed to the plasma, with the modification
35 corresponding to introducing into the disturbed region defects, disturbances, and disorders at atomic scale

(weakening of atomic bonds, changing of bond angles, ...).

This alteration serves to improve bonding between wafers - and in particular to increase bonding energy.

5 This alteration is characterized by an etching speed that is higher than the etching speed that is observed on a non-activated wafer.

Such a "disturbed" region is etched more quickly than a non-activated wafer (for example wet etching of
10 the surface clean No. 1 (SC1) type using $\text{NH}_4\text{OH} + \text{H}_2\text{O}_2 + \text{H}_2\text{O}$).

By way of example, for wet etching of the SC1 type ($\text{NH}_4\text{OH} + \text{H}_2\text{O}_2 + \text{H}_2\text{O}$) carried out for three minutes (at constant temperature), the following etching thicknesses
15 are observed for layers of different materials:

- non-treated silicon oxide layer (i.e. a substrate having a surface layer of SiO_2): 6 Å;
- implanted silicon oxide layer (using hydrogen for layer transfer by a method of the Smart CutTM type): 20 Å;
- 20 and

- for a silicon oxide layer that has been "disturbed" in the meaning of the present specification, by using plasma exposure: 37 Å. It is specified that this value of 37 Å is the same regardless of whether or
25 not the layer has been implanted.

These results show that the disturbance created by plasma activation can be characterized by a significantly increased etching speed.

The above results were obtained for an etching
30 solution at a temperature of 70°C (SC1 solution).

It is specified that the increase in etching speed observed on a wafer of material that has been "disturbed" in the meaning of the present specification increases with increasing temperature at which etching is
35 performed.

The etching speed information provided above in the context of a wafer of material that has been subjected to

implantation illustrates the fact that a material that has been "disturbed" in the meaning of the present specification is characterized by an etching speed that is even faster than that observed on a material of the same type that has not been "disturbed", but that has
5 been implanted.

Concerning the increase in etching speed observed in a material that has been altered by plasma activation, reference can be made to the article "Effect of plasma
10 activation on hydrophilic bonding of Si and SiO₂", J. of Electrochem. Soc., Vol. 149, No. 6, p. 348 (2002) by T. Suni et al.

The disturbed region obtained in the context of the invention typically extends in the thickness of the wafer
15 whose surface has been activated to a depth lying in the range 10 Å to 250 Å.

The "species" mentioned above are typically ions of the plasma.

Control over the activation parameters typically
20 seeks to obtain kinetic energy for said species contained in the plasma at levels lying in the range 10 eV to 2 keV.

Finally, it is specified that control of the activation parameters preferably comprises controlled
25 variation of at least some of the parameters.

Such control variation makes it possible specifically to obtain a disturbed region that is continuous and uniform (e.g. by varying power, whether
30 power serving to constitute the different depths of the disturbed region in the thickness of the wafer that is being activated).

In general, this control variation of the activation parameters is preferably implemented so as to obtain high
35 kinetic energy for the ions at the beginning of activation and lower kinetic energy towards the end of activation.

Configuration of the plasma-generating installation

The invention is implemented in an installation comprising a plasma enclosure in which the pressure and
5 the composition of the atmosphere are controlled.

There exist several types of such installation.

The invention can be implemented in an installation of the RIE type comprising a single RF generator feeding an electrode supporting the wafer for activation via
10 capacitive coupling.

It is the single RF generator that serves to generate the plasma (i.e. to excite the species).

The "power" referred to in this specification and constituting one of the activation parameters is more
15 precisely the power of said generator connected to the electrode in contact with the wafer to be activated.

The plasma enclosure has a second electrode that is not connected to the wafer to be activated. This second electrode is not connected to any generator.

20 In this variant, controlling the power of the sole generator (which is connected to the electrode in contact with the wafer to be activated) serves both to excite the plasma and to control the kinetic energy of the plasma ions that bombard the surface of the wafer to be
25 activated.

It is specified that it is also possible to implement the invention in an installation similar to that described above, but in which the same electrode is connected to a second RF generator.

30 Under such circumstances, it is the second RF generator (connected to the electrode with which the wafer to be activated is not in contact) that excites the plasma. The second generator is thus controlled to control the density of the plasma.

35 In this variant, controlling the power of the first generator (which is connected to the electrode in contact with the wafer to be activated) serves solely to control

the kinetic energy of the ions in the plasma that bombards the surface of the wafer to be activated.

Controlling power density

5 As mentioned above, it is possible to control activation parameters by controlling the density of the power fed to an electrode connected to the wafer whose surface to be activated.

10 The Applicant has found that applying greater power has the effect of increasing the thickness of the resulting disturbed region.

15 This is illustrated in Figure 2 in which the power density used for activating the plasma is plotted along the abscissa in W/cm², and the thickness of the disturbed region created by the activation is plotted up the ordinate in Å.

Each point in the graph of this figure corresponds to a different power level.

20 It is specified that the spots of this curve were acquired for wafers having a diameter of 300 mm (black diamonds) or a diameter of 200 mm (two black crosses, the cross on the left corresponding to a power of 250 W and the cross on the right corresponding to a power of 1000 W).

25 It is also specified that the "power" that is controlled in the context of the invention is the power of the electrode connected to the wafer to be activated, for the purpose of controlling the kinetic energy of the ionized species of the plasma.

30 When controlling power, the power density is varied by initially applying high power, and subsequently applying low power, i.e. power at a level that is lower than the high power.

35 Variation between high power and low power can be performed in power steps, with one power of step corresponding to high power and another power step corresponding to low power.

This is illustrated by two of the three curves plotted using continuous lines in Figure 3.

In this figure, the curves drawn in dashed lines corresponding to prior art conditions, where power is
5 kept constant throughout activation.

The level corresponding to high power and the level corresponding to low power are each maintained for a duration lying in the range 5 s to 60 s, and preferably in the range 10 s to 30 s.

10 It is also possible to cause power to vary from high power to low power in continuous manner by causing the power to decrease from high power down to low power.

This is illustrated by the curve in Figure 3 that presents a slope that is continuous between an initial
15 high power and a final low power.

This continuous variation is typically performed over a time interval of duration lying in the range 10 s to 2 min.

The high and low power levels are defined as a
20 function of the area of the surface to be activated.

The high power level typically has a value lying in the range 1.5 W/cm² to 15 W/cm² over the surface to be activated, and the low power typically has a value lying in the range 0.15 W/cm² to 1.5 W/cm² over the surface to
25 be activated.

More precisely, it is possible to select a high power having a value of 3 W/cm² over the surface to be activated, and a low power having a value of 0.8 W/cm² over the surface to be activated.

30 Under such circumstances, and for a wafer to be activated having a surface in the form of a disk with a diameter of 200 mm, the high power has a value of 1000 W and the low power has a value of 250 W.

For a wafer to be activated whose surface in the
35 form of a disk having a diameter of 300 mm, the high power has a value of 2000 W and the low power has a value of 500 W.

Controlling gas composition

It is also possible to control activation parameters by controlling the composition of the gas from which the plasma is created.

This type of control can be implemented in combination with controlling power in a manner described above, or it may constitute the only control applied.

Said control of gas composition is implemented to obtain controlled variation in the nature of the gas used for generating the plasma.

This variation consists in treating the surface to be activated with a plasma obtained from a first gas and subsequently with a plasma obtained from a second gas.

Said first gas is preferably made up of one or more species that is/are lighter in weight than said second gas.

Specifically this makes it possible:

- at the beginning of activation, to cause the species of the first gas to penetrate more deeply into the wafer to be activated; and
- towards the end of activation, to finish off making the disturbed region by causing second species to penetrate into the wafer to be activated, the second species being heavier and therefore penetrating to a shallower depth in the wafer to be activated.

For example, the first gas may be helium and the second gas may be oxygen or argon. In another example, the first gas may be oxygen and the second gas argon.

The first and/or second gas may also be constituted by a mixture of gases - e.g. a mixture between a species that is to be ionized (e.g. Ar or O₂), and a species that is to remain neutral (non-ionized), but that serves to dilute and determine the quantity of the species that is ionized (which non-ionized species may be constituted by helium, for example).

Controlling pressure

It is also possible to control the activation parameters by controlling the pressure in the plasma.

Here again, this control may be performed on its own, or in combination with at least one of the above-described controls (power, composition).

Pressure can be controlled so as to be lower at the beginning of activation and higher towards the end of activation.

In general, it is desired to obtain activation at higher kinetic energy at the beginning of activation and activation at lower kinetic energy subsequently. A lower pressure leads to a higher level of kinetic energy.

Typical pressure values lie in the range 5 millitorr (mTorr) to 10 Torr, and preferably in the range 20 mTorr to 100 mTorr.

Increase in bonding energy

Under all circumstances, the activation parameters are controlled for the purpose of creating a disturbed region in the thickness of said surface region of the wafer whose surface has been activated.

This disturbed region is preferably a region that is uniform and continuous with increasing depth in the wafer.

Nevertheless, and alternatively, it is possible by means of the invention to create a plurality of disturbed regions in the thickness of the surface region of the wafer whose surface has been activated, with each of these disturbed regions extending over a respective depth in the thickness of said wafer and having a respective thickness.

The invention makes it possible significantly to increase the bonding energy obtained after bonding together surfaces, at least one of which has been activated in accordance with the invention.

In this respect, Figure 4 shows the bonding energy (in mJ/m²) obtained for four different activations, all performed on only one of the surfaces to be bonded together - specifically the surface of an Si wafer that was surface oxidized and that was subsequently implanted for the purpose of transferring a thin layer by a method of the Smart CutTM type.

The other surface (which was that of an Si wafer) was not activated in the examples shown in this figure.

10 This figure shows more particularly the effect of appropriately selecting variation in activation power on the bonding energy that is obtained (the other activation parameters remaining the same for all four activations).

The dashed line in the bottom portion of the graph in this figure represents the level of bonding energy that would be obtained without activation.

Each respective activation is represented by the mean of a plurality of measurement points.

From left to right in the figure the four activations shown correspond to the following sets of power conditions:

- a constant value of power (250 W for 30 s);
- a constant value of power (1000 W for 30 s);
- varying power comprising 250 W for 15 s followed by 1000 W for 15 s;
- varying power comprising 1000 W for 15 s followed by 250 W for 15 s.

A significant increase in bonding energy is observed in the fourth set of conditions.

30 This figure thus shows that controlling the power can lead to a very significant increase in the bonding energy.

It also shows that this increase is obtained by implementing high power initially followed by low power subsequently.

It is desirable to prepare the portion of the disturbed region that is buried the most deeply before preparing the shallower portion of said region.

Controlling activation parameters continuously (in this case controlling power continuously), serves to create a disturbed region in continuous manner of depth and thickness that are well controlled, while ensuring that the disturbed region is uniform.

This increase in bonding energy makes it possible in particular to activate only one of the surfaces that are to be bonded together, which constitutes an advantage.

The fact of activating only one of the surfaces for bonding corresponds to a saving in time.

This also makes it possible to restrict the contamination in metals and particles that is the result of exposure to the plasma to a single surface only, and thus to:

- reduce the overall level of such contamination; and
- limit the cleaning operations that might be necessary between activation and bonding to a single surface.

Furthermore, it is possible to envisage bonding together two surfaces, one of which is incapable of withstanding plasma activation, while nevertheless obtaining good bonding energy. For example, it is possible to bond a substrate covered in a fragile material with a wafer (e.g. having a surface of Si or of SiO₂), by activating said wafer only.

30

An implementation example

By way of non-limiting example and in addition to the values set out above, it is possible to implement activation and bonding of an Si wafer with another Si wafer that is surface oxidized by performing the following sequence:

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- preparing the two surfaces for bonding together (wet cleaning of the RCA (Radio Corporation of America) type, etc., polishing, ...);

- plasma activation of one or both of the surfaces for bonding together by "double power" treatment: a "Toyko Electron Limited" (registered trademark) plasma machine can be used for wafers having a diameter of 200 mm, using a pressure of 50 mTorr under an atmosphere of O₂, with an O₂ flow rate of 75 standard cubic centimeters per minute (sccm), and a power of 1000 W for 15 s and then 250 W for the following 15 s;

- optional cleaning of the surfaces immediately prior to bonding (rinsing in deionized water, RCA type or NH₄OH type cleaning, scrubbing with water, ...;

- putting the surfaces for bonding together into contact and initiating bonding; and

- reinforcing the bonding by heat treatment (at low temperature, e.g. 200°C).

As stated, the invention can be implemented in the context of a transfer method - e.g. a method of the Smart Cut™ type, for making multilayer wafers (in particular of the silicon-on-insulator (SOI) type).

WHAT IS CLAIMED IS:

1. A method of bonding together two wafers made of materials selected from semiconductor materials, said method implementing plasma activation of the surface of
5 at least one of the two wafers to be bonded together, and comprising, during plasma activation, controlling the activation parameters to modify the kinetic energy of the species contained in the plasma in order to create a disturbed region of controlled thickness in the thickness
10 of a surface region of the wafer whose surface is being activated.
2. A method according to claim 1, wherein said control of the activation parameters also serves to control the
15 maximum depth of said disturbed region in said wafer whose surface is being activated.
3. A method according to claim 1, wherein said control of the activation parameters comprises controlled variation
20 of said parameters.
4. A method according to claim 2, wherein said disturbed region extends in the thickness of said wafer whose surface is being activated between a depth of 10 Å and a
25 depth of 250 Å.
5. A method according to claim 1, wherein said species are the ions of the plasma.
- 30 6. A method according to claim 1, wherein said control seeks to obtain kinetic energy for said species contained in the plasma at a level lying in the range 10 eV to 2 keV.
- 35 7. A method according to claim 1, wherein said control of the activation parameters comprises controlling kinetic energy by controlling the power density fed to an

electrode connected to the wafer whose surface is to be activated.

8. A method according to claim 7, wherein said power
5 density is controlled in such a manner as to achieve controlled variation in the density of the power generating the plasma.

9. A method according to claim 8, wherein said power
10 density is caused to vary by initially applying "high" power, and subsequently applying "low" power that is lower than the high power.

10. A method according to claim 9, wherein variation
15 between high power and low power is performed in power steps, one power step corresponding to high power, and another power step corresponding to low power.

11. A method according to claim 10, wherein the step
20 corresponding to high power and the step corresponding to low power are each carried out for a duration lying in the range 5 s to 60 s.

12. A method according to claim 11, wherein the step
25 corresponding to high power and the step corresponding to low power are each carried out for a duration lying in the range 10 s to 30 s.

13. A method according to claim 9, wherein variation
30 between high power and low power is performed by causing the power to decrease in continuous manner from the high power down to the low power.

14. A method according to claim 9, wherein the high power
35 has a value lying in the range 1.5 W/cm² to 15 W/cm² of the area to be activated, and the low power has a value

lying in the range 0.15 W/cm^2 to 1.5 W/cm^2 of the area to be activated.

15. A method according to claim 14, wherein the high
5 power has a value of 3 W/cm^2 of the area to be activated
and the low power has a value of 0.8 W/cm^2 of the area to
be activated.

16. A method according to claim 15, wherein the surface
10 of the wafer to be activated is a disk having a diameter
of 200 mm, the high power has a value of 1000 W, and the
low power has a value of 250 W.

17. A method according to claim 16, wherein the surface
15 of the wafer to be activated is a disk having a diameter
of 300 mm, the high power has a value of 2000 W, and the
low power has a value of 500 W.

18. A method according to claim 14, wherein the plasma is
20 generated by equipment of the RIE type having a single RF
generator feeding the electrode supporting the wafer to
be activated via capacitive coupling.

19. A method according to claim 17, wherein said
25 variation is performed over a time interval of duration
lying in the range 10 s to 2 min.

20. A method according to claim 7, wherein said electrode
connected to the wafer whose surface is to be activated
30 is used solely for controlling the kinetic energy of the
plasma species.

21. A method according to claim 7, wherein said electrode
connected to the wafer whose surface is to be activated
35 is used both for controlling the kinetic energy of the
plasma species, and for exciting the plasma.

22. A method according to claim 1, wherein said control of the activation parameters comprises controlling the kinetic energy by controlling the composition of the gas in which the plasma is created.

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23. A method according to claim 22, wherein said control of gas composition is performed to obtain controlled variation in the nature of the gas used for generating the plasma.

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24. A method according to claim 23, wherein said variation consists in treating the surface to be activated with a plasma obtained from a first gas, and subsequently with a plasma obtained from a second gas.

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25. A method according to claim 24, wherein said first gas is made up of one or more species that is/are lighter in weight than said second gas.

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26. A method according to claim 25, wherein said first gas is helium and said second gas is oxygen or argon, or said first gas is oxygen and said second gas is argon.

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27. A method according to claim 24, wherein the first and/or second gas is/are a gas mixture, e.g. a mixture between a species that is to be ionized (Ar or O₂, for example) and a species that is to remain neutral (non-ionized), but that serves to dilute and determine the quantity of the ionized species (the non-ionized species may be constituted by helium, for example).

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28. A method according to claim 1, wherein said control of the activation parameters comprises controlling kinetic energy by controlling the pressure in the plasma.

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29. A method according to claim 28, wherein said control of pressure is implemented to obtain controlled variation in pressure.

5 30. A method according to claim 29, wherein said controlled variation in pressure consists in controlling the pressure to occupy a "low" level initially during activation, and then subsequently a "high" level that is greater than said low level.

10 31. A method according to claim 1, wherein said control of the activation parameters is implemented in order to create a single disturbed region in the thickness of said surface region of the wafer whose surface is being
15 activated.

32. A method according to claim 1, wherein said control of the activation parameters is implemented in order to create a plurality of disturbed regions in the thickness
20 of said surface region of the wafer whose surface is being activated, each of said disturbed regions extending over a respective depth in the thickness of said wafer.

33. A method according to claim 1, wherein, in order to
25 perform said bonding, the surface of only one of the two wafers that are to be bonded together is subjected to plasma activation.

34. A method of transferring a thin layer of
30 semiconductor material from a top wafer forming a donor substrate to a base wafer forming a receiver substrate, the method implementing bonding according to claim 1 in order to bond a surface of said donor substrate to a surface of said receiver substrate.

35 35. A method according to claim 34, wherein said transfer method is implemented using the Smart Cut™ method

implementing weakening implantation prior to bonding in order to create a zone of weakness in the thickness of the donor substrate, followed by detachment at said zone of weakness after bonding.

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36. A method according to claim 35, wherein, after implantation and prior to bonding, the oxidized surface of said donor substrate is subjected to plasma activation.