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## Surface activation and direct bonding of semiconductor wafers

### Patent

#### How to cite:

Braithwaite, Nick; Al-Kuzee, Jafar; Lima, Paulo and Kowal, Jan (2009). Surface activation and direct bonding of semiconductor wafers. The Open University, GB 2458256.

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Version: Not Set

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(21) Application No: 0708109.4  
(22) Date of Filing: 26.04.2007  
(30) Priority Data:  
(31) 0609167.2 (32) 10.05.2006 (33) GB

(51) INT CL:  
H01J 37/32 (2006.01) H01L 21/302 (2006.01)  
H01L 21/306 (2006.01)

(56) Documents Cited:  
EP 1518669 A2 JP 640001234 A  
JP 580212129 A

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(58) Field of Search:  
INT CL C23C, H01J, H01L  
Other: EPODOC, WPI

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(54) Abstract Title: **Surface activation and direct bonding of semiconductor wafers**

(57) An apparatus for surface activation treatment of a substrate 101 comprises first and second electrodes 102, 103 for generating a plasma, and a substrate mount disposed perpendicular to the electrodes 102, 103. The electrodes 102, 103 define a plasma generation region 100 which is separated from the substrate mount. At least one of the electrodes 102, 103 has perforations which allow active neutral species generated in the plasma to diffuse on to substrate 101 to treat the substrate surface whilst restraining charged species of the plasma. A method of pre-bonding treatment of one or more substrates 101 comprises exposing the surface of the one or more substrates 101 to active neutral species created locally by non-equilibrium electrical discharges. The apparatus and methods disclosed reduce substrate surface damage by using indirect plasma exposure.

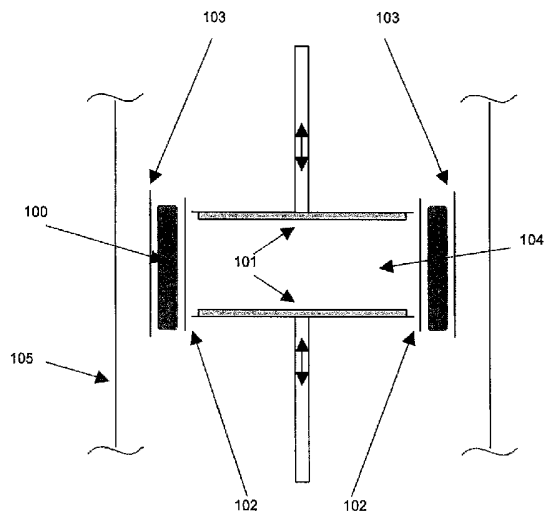


Figure 2

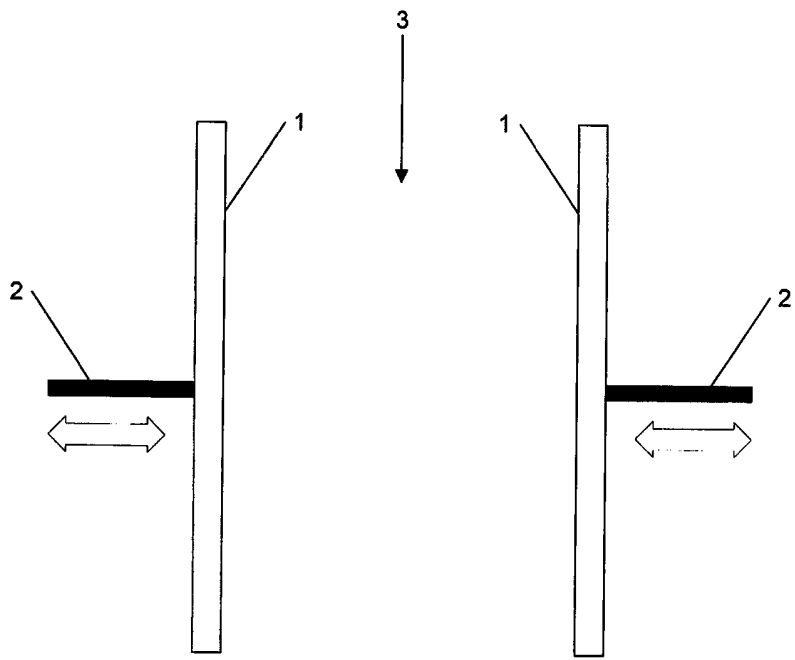


Figure 1

2/2

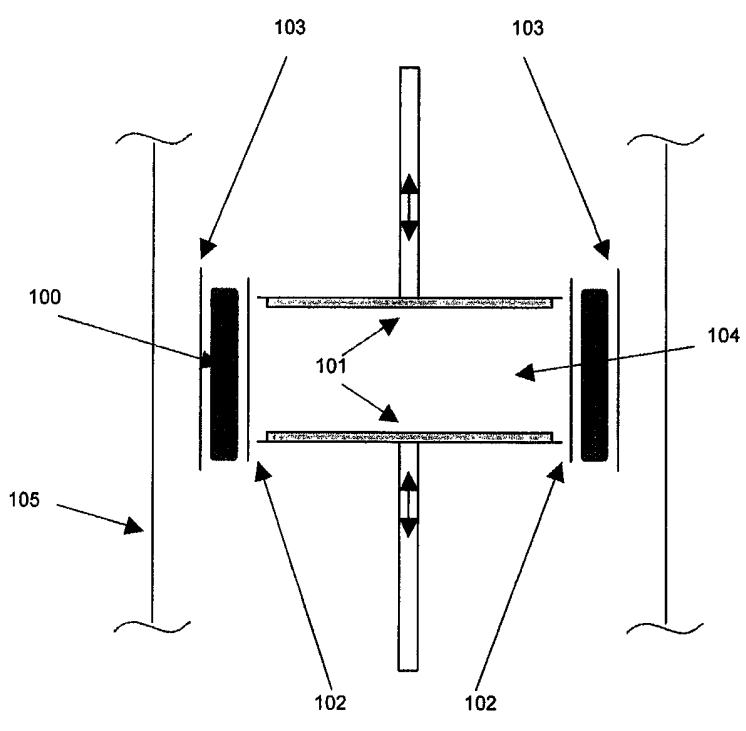


Figure 2

Semiconductor bonding techniques

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The invention is concerned generally with semiconductor bonding techniques.

Direct wafer bonding, i.e. two wafers directly bonded to each other without the use of adhesives, alloying etc, is an enabling technology in the electronics industry for the creation of semiconductor devices. Examples of such bonding are silicon on insulator, SOI (in the form of silicon on silicon oxide) and strained silicon wafers, sSOI (silicon-germanium on silicon, for example). In sSOI technology, silicon is grown epitaxially on silicon-germanium (SiGe) layers. The lattice constant of SiGe is higher than that of silicon. This results in the 'straining' of the silicon lattice. In the strained silicon, electrons experience less resistance resulting in a higher electron mobility. The strained silicon grown on the SiGe substrate can then be transferred to a thermally oxidised silicon wafer, leading to the formation of strained silicon-on-insulator.

Direct silicon wafer bonding also has significant applications beyond purely electronics, such as in micro (and nano-) electromechanical systems, M(N)EMS. This technology uses wafer-scale lithography techniques to build electromechanical devices on silicon and other substrates. New opportunities in this technology are opened up if components are fabricated from one or more parts that have been separately fashioned. Therefore, this introduces a requirement for joining these parts together, and the condition of the surfaces to be joined is of crucial importance.

Many methods are used for joining semiconductor components, including mechanical fastening, adhesive bonding, soldering and welding. However, at the M(N)EMS level, none of these joining techniques is viable. Where one of the materials to be joined is glass, then interfacial mixing can be promoted electrically in a process known as anodic bonding. However, this process does not work when bonding one semiconductor to another.

A method of joining, suitable for M(N)EMS might involve direct fusion bonding. This is a method in which the adhesion of two highly polished surfaces occurs as a result of chemical bonding between constituent atoms of the two surfaces. This adhesion is weak  
5 at room temperature (only Van der Waals forces and relatively weak hydrogen bonds contribute). However, maximum strength is achieved by converting these weak bonds into covalent bonds through a high temperature thermal annealing process.

Direct fusion bonding usually requires annealing temperatures in the range of 800°C-  
10 1000°C for several tens of minutes to achieve adequate strength. It is these high temperatures that are a key drawback to the use of fusion bonding, since they limit the types of material that can be present on the wafers before they are joined. Pre-processed wafers that already contain doped regions, with their temperature-sensitive diffusion profiles, cannot be subjected to prolonged high temperature annealing. High  
15 temperature annealing can also induce material degradation. When bonding dissimilar materials, the high temperatures cause considerable thermal stress due to differences in thermal expansion. For applications using fully processed wafers such as M(N)EMS devices, the maximum temperature allowed is less than 400°C because the aluminium metallization used for interconnections and bond pads forms a eutectic mixture with  
20 silicon just above this temperature.

In order to overcome high temperature annealing problems, current technology uses 'surface activation' methods. This dramatically reduces the severity of the thermal cycle required to effect strong interfacial bonding between wafers of semiconductor materials.  
25 These technologies are based on pre-treatment of the surfaces to be adhered, in order to change and control the bonding mechanism. After surface activation, high energy bonds can be formed at lower temperatures compared with direct fusion bonding processes. There are two main methods of pre-treatment; (i) wet activation and (ii) dry activation.

30 Wet activation can be achieved by the dipping of substrates in various chemical solutions. The second method, dry activation, involves subjecting the substrate surface to a plasma generated by electrical discharge through gases.

These surface activation methods render the surfaces of the wafers hydrophilic and favourable to bonding. Dry activation has some significant advantages over wet activation. Certain substrates (in particular, micromechanical wafers for M(N)EMS applications) are not suited to wet activation as the liquid can damage sensitive mechanical structures. In addition, wet activation demands a drying phase. This not only increases the total process time, but also exposes any fine structures to additional stress.

Existing methods based on plasma technology have been able to reduce the annealing temperature from approximately 1000°C to 200-300°C. One such method uses a low pressure plasma to which bond surfaces are exposed prior to bringing them together (EVG patent: US2004132304). Another technique involves a pre-treatment in which wafers are exposed to a plasma in a gas at atmospheric pressure (SUSS patent: EP1568077). However, these techniques have a number of disadvantages including the degradation of the surface, due to direct exposure to the plasma. It is known that ion bombardment and the accumulation of charge at the wafer surface can damage the surface, and this has a detrimental effect on the bonding process.

Further background art may be found in EP 1518699, US 2005/0042869, JP 2003197606, US 2003/0168145, WO 2006/038030, US 4615905, US 2004/0237894 and the papers "Void-free silicon-wafer-bond strengthening in the 200–400 °C range" (Kissinger et al, Institute for Physics of Semiconductors, Frankfurt (Oder) GmbH, Walter-Korsing-Strasse 2, Frankfurt, 0-1200 Germany) and "Application of oxygen plasma processing to silicon direct bonding" (Zucker et al, Solid State Electronics Laboratories, Technical University of Darmstadt, D-6100 Darmstadt Germany, Robert Bosch GmbH, D-7410 Reutlingen Germany).

Aspects of the present invention concern methods for dry pre-treatment without exposure of bond surfaces to a plasma, thereby preventing surface damage. A particularly effective and novel alternative to the existing low pressure and high pressure plasma exposures has been developed. This method is based upon exposure of the surfaces to be adhered to species that have been generated in a plasma, but importantly the wafer is protected from strong UV photon fluxes, ion bombardment and

charge accumulations that appear to have a deleterious effect on the bonding process. This method involves the promotion of surface chemical and physical interactions with active neutral species such as oxygen radicals, while avoiding surface damage and surface migration that are likely consequences of exposure to the charged components of the plasma. A pulsed method may protect the wafer from ion bombardment and photon fluxes by drastically reducing the proportion of the time when this is happening, but the method described herein is more effective and essentially avoids the deleterious effects of plasma exposure.

10 This new process offers benefits over the existing technologies which both involve the direct exposure of the wafer surface to the plasma, which is deleterious. However, this new process uses chemical reactions that follow exposure of the surfaces to species generated in a plasma, without direct exposure of bond surfaces to the plasma, or without substantial direct exposure to the plasma, therefore avoiding surface damage.

15 We describe herein in certain embodiments a process for the treatment of flat substrates, involving brief exposure to species generated in an electric plasma.

We describe herein in certain embodiments a cylindrical shell design of the radical generator. The cylindrical shell design differentiates aspects of the present invention from other mesh-based means of protecting the wafer from ion damage by forcing any high energy ions that do get through the mesh to move in a direction that is predominantly parallel to the wafer surface. By contrast, the protection offered by systems that have their meshes facing the wafer surfaces is very limited, as many ions will get through the mesh holes, and these will have most of their momentum directed towards the surface that is being activated.

20 According to an aspect of the present invention, there is provided an apparatus for surface activation treatment of a substrate, the apparatus comprising: first and second electrodes for generating a plasma, the electrodes defining a plasma generation region between the electrodes; and mounting means for mounting said substrate substantially perpendicular to the electrodes; wherein at least one of said electrodes has perforations for allowing active neutral species generated, in use, in the said plasma to diffuse to the



said substrate to treat the said substrate, whilst restraining charged species of the said plasma. In preferred embodiments, one of said electrodes has said perforations.

5 An advantage of arranging the electrodes so that the substrate lies substantially perpendicular to the electrodes (that is, parallel to the direction of the electric field in the vicinity of the electrodes) is that the charged species of the plasma are much less likely to reach the surface of the substrate, because the component of their velocity due to being accelerated in the electric field lies parallel to the substrate. Thus the electrodes define an electrostatic cage to contain the plasma, from which active neutral species 10 may diffuse in order to reach the substrate. Those of the charged species which do escape the confines of the electrostatic cage (by passing through the perforations of the perforated electrode) move largely in a direction parallel to the substrate rather than towards it. Components of their velocity perpendicular to the substrate (which may cause the charged species to move towards the substrate) are likely to be very much 15 smaller in magnitude because these are due to thermal kinetic energy rather than kinetic energy due to acceleration in an electric field. Only by colliding with background gas molecules can the charged species acquire more momentum in the direction of the substrate, and such a collision is likely to transfer much of the charged species' kinetic energy to other molecules anyway.

20

In this specification, where we refer to charged particles moving parallel to a surface, we mean that the charged particle moves parallel to the line that depicts the substrate's surface if one were to draw that substrate in cross-section.

25 The electrostatics of a single mesh restrain negative charge. The positive charge is restrained by the electric field geometry, which prevents un-collided ions from impacting the surface. A double meshed arrangement could also contain the positive charge purely electrostatically, as could a multiple grid structure.

30 As the skilled person will appreciate, this arrangement is most effective with the substrate parallel to the electric field in the vicinity of the perforated electrode, but also applies at other angles, the effect being maximised when parallel. With planar electrodes (or cylindrical electrodes, these being linear in one direction), the electric

field is perpendicular to the electrodes, therefore the substrate may be disposed substantially perpendicular to the electrodes. Where the first and second electrodes define an electric field in the vicinity of the electrodes, this may comprise an electric field between the electrodes.

5

The skilled person will also be aware that, while a major application of surface activation treatment is for preparing substrates for bonding, another application is cleaning.

10 According to another aspect of the present invention, there is provided a method for surface activation treatment and bonding of a pair of substrates, the method comprising: mounting a first substrate substantially perpendicular to first and second electrodes, the electrodes defining a plasma generation region between the electrodes; mounting a second substrate substantially parallel with said first substrate; applying a potential  
15 between first and second electrodes to generate a plasma; and bonding said first and second substrates by moving said substrates into contact with one another and applying pressure thereto; wherein at least one of said electrodes has perforations for allowing active neutral species generated in the plasma to diffuse to the substrates to treat the substrates, whilst restraining charged species of the plasma. Either or both of said  
20 substrates may be moved to achieve contact. Hereinafter reference to a substrate should be taken also to include a pair of substrates disposed in a like manner to above. The invention further provides apparatus comprising means for carrying out the above method steps.

25 According to a further aspect of the present invention, there is provided a method for surface activation treatment of a substrate, the method comprising applying a potential between first and second electrodes to generate a plasma between the electrodes, the electrodes defining a plasma generation region between the electrodes, said substrate being disposed outside said plasma generation region, and allowing active species  
30 generated in the plasma to diffuse to said substrate, to treat said substrate.

Preferably the potential is in the range 100V to 1000V, e.g. 200V or 500V. Preferably the potential is applied for a duration in the range 2 seconds to 600 seconds, e.g. 5, 10,

20, 50, 100 or 200 seconds. The electrodes may comprise annular or planar electrodes, preferably annular. The potential may comprise a DC voltage or an AC voltage (e.g. line rate 50Hz or 60Hz). Alternatively a radio or microwave frequency potential may be used (e.g. 2 MHz, 5 MHz, 10 MHz, 20 MHz, 50 MHz or 2.45 GHz). An allocated  
5 frequency may be used, for instance 13.56 MHz, if it is useful to exploit the opportunities offered by using an allocated STM (science, technology, medicine) frequency. Using a radio or microwave frequency potential allows a lower potential to be used. Preferably the surface activation treatment takes place at a pressure commensurate with diffusive transport (a diffusive transport pressure, i.e. a pressure at  
10 which diffusive transport may occur), for example a pressure in the range 10Pa to 1000Pa (e.g. 20, 50, 100, 200 or 500Pa), preferably 13Pa to 130Pa.

According to a yet further aspect of the present invention, there is provided a method for surface activation treatment of a substrate, the method comprising: applying a potential  
15 between first and second electrodes to generate a plasma between the electrodes, the electrodes defining a plasma generation region between the electrodes, said substrate being disposed outside said plasma generation region, the electrodes defining an electrostatic cage perpendicular to said substrate to sandwich the plasma, the electrostatic cage having an inner mesh or other porous surface to allow active neutral  
20 species generated in the plasma to diffuse to said substrate, to treat said substrate whilst restraining charged particles by electrostatic potentials. The mesh or other porous surface may be defined by one or more of the electrodes.

According to another aspect of the present invention, there is provided an apparatus for  
25 surface activation treatment of a substrate, the apparatus comprising first and second electrodes for generating a plasma, the electrodes defining a plasma generation region between the electrodes, said substrate being disposed outside said plasma generation region, and means for allowing active species generated in the plasma to diffuse to said substrate, to treat said substrate.

30

Preferably the electrodes comprise annular electrodes, although they may comprise planar electrodes. Preferably at least one of the electrodes comprises a mesh, for example an annular mesh electrode. The mesh may also comprise a multiple grid

structure set at different potentials so that both positive and negative charge might thereby be effectively contained. The means for allowing active species to diffuse may comprise a mesh electrode, so that active species may diffuse through the holes in the mesh. The mesh electrode may comprise one of the first and second electrodes. The apparatus may be contained in a pressure vessel for maintaining a constant pressure. The substrate may be disposed from the electrodes at a distance no greater than the distance that allows the active species to attain a uniform concentration over the substrate surface. This is governed by the two processes of diffusion and decay of the active species.

10

According to a further aspect of the present invention, there is provided an apparatus for surface activation treatment of a substrate, the apparatus comprising: first and second electrodes for generating a plasma, the electrodes defining a plasma generation region between the electrodes, wherein the said substrate, in use, is disposed outside said plasma generation region, the electrodes defining an electrostatic cage perpendicular to the said substrate to sandwich the plasma, said electrostatic cage having an inner mesh or other porous surface to allow active neutral species generated in the plasma to diffuse to the said substrate, to treat the said substrate whilst restraining charged particles by electrostatic potentials.

15

According to a yet further aspect of the present invention, there is provided a method for a pre-bonding treatment to one or both surfaces by means of exposure to the active neutral species created locally by means of non-equilibrium electrical discharges so arranged as to substantially or totally exclude charged species from the treatment environment.

20

Features of the above described aspects of the invention may be combined in any combination.

Embodiments of these and other aspects of the invention will now be described in further detail, with reference to the accompanying drawings, in which:

25

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Figure 1 shows an apparatus for use with a method of treating flat substrates according to an aspect of the present invention.

5 Figure 2 shows an apparatus for treating flat substrates according to another aspect of the present invention.

The present method is based on exposure of a substrate, for example a wafer to be treated, to species that have been generated in a plasma but importantly the wafer is protected from prolonged photon flux, ion bombardment and charge accumulations that appear to have a deleterious effect on the bonding process. In effect we are promoting surface reactions to active species such as oxygen or hydroxyl radicals while avoiding the surface damage and surface migration that are likely consequences of exposure to the charged components of a plasma. Without wishing to be bound by theory, activation is achieved, we believe, by a superficial effect relating to the chemical reactivity of the terminal groups.

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The process can operate in either a DC or AC mode, typically 500V. It can also be operated at a slightly lower voltage from a radio frequency source, typically 200V at 13.56 MHz. The process pressure may be in the range of 13-130Pa. Alternatively the pressure range may comprise 0.1 to 1 Torr, or up to 1000Pa. The time scale for diffusion of species in the gas phase depends upon pressure and may be of the order of tenths of seconds to low numbers of seconds. The treatment time is typically in the range of 2 - 600 seconds. The process of bonding is initiated by bringing the two surfaces into contact in an environment of reduced gas pressure or at atmospheric pressure (although this does not appear to be a critical issue).

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A number of embodiments of the invention are described. In the first (shown in Figure 1), a plasma is created between two of the surfaces (1) to be treated using a pulse of radio frequency power lasting only a few microseconds, then the plasma is extinguished and a period of several tens of microseconds passes during which time active species diffuse to and find surface sites. Pulsed plasma, since the plasma exists for only a tiny fraction of the cycle, is one way of sparing a surface from damage by charged particles. The pulse may be applied by electrodes at the supports (2) holding the surfaces to be

30

treated, or alternatively mechanical supports holding the surfaces may be separate from electrodes used to apply the pulse. Optionally more than one pulse may be applied to achieve the desired level of surface treatment. The distance between the surfaces may be varied as shown by the double-headed arrows in the Figure, to control a volume  
5 between the surfaces (3) for the plasma, and the surfaces may be brought together after treatment.

A preferred embodiment is shown in Figure 2, and may be considered as a 'plasma shell'. Active species are generated in a ring of plasma (generation region / annular  
10 plasma 100) contained between two electrodes 102, 103 around the edge of one or more circular wafers (surfaces to be treated 101). The wafers are disposed perpendicular to the electrodes, and hence parallel to the electric field generated. Conditions are such that charged particles are again restrained by electrostatic potentials and meshes while neutral species are able to diffuse right across the surface of the wafer.

15 The electrode geometry may be either planar (for the pulsed method and the intermediate electrode method) or else it may be a co-axial cylindrical arrangement with the inner surface being a mesh or other porous material with a high transmission to active species. Figure 2 shows a mesh inner ring electrode 102 and an outer ring  
20 electrode 103. The activation volume 104 may be within the inner ring electrode. The apparatus may be contained in a vessel 105. The distance between the surfaces to be treated may be varied as indicated by the double-headed arrows. The surfaces may be brought together after treatment. Alternatively, the surface (105) may be of metal to provide further electrostatic screening, the whole being immersed in some larger vessel.

25 Other systems for separating the plasma region from the surface of the substrate to be treated do this by interposing a perforated collecting electrode. The intention is that charged particles generated within the plasma are collected and neutralized on the facing surface material of the perforated electrode, thus preventing them from reaching  
30 the substrate. Indeed, such a perforated electrode will be effective in reducing the flux of charges. Any detrimental effects arising from high-energy impacts between charged particles and the substrate are thereby lessened, though they are not eliminated altogether as some fraction of charges will leak through the perforations. The flux of

active neutral particles from the plasma, needed for the treatment of the substrate, is less affected and passes through the perforations. The neutral species are then able to interact with the substrate, producing the intended chemical changes to that surface.

- 5 Such 'in-line' systems are only partially effective in preventing impacts of charged particles with the substrate surface. This is because close to the electrode some charges may be accelerated by the electric field towards the plane of the collector electrode, but do not all hit the electrode surface – a significant proportion passes through the perforations, being too distant from the edge of the perforation to strike the metal of the
- 10 electrode before having passed through into the essentially field-free space between the collecting electrode and the substrate. A multiple mesh assembly could be deployed to cut-off the flux of these charges electrostatically, by placing the second mesh outside the first at a potential so as to repel them. Alternatively, this charge can be restrained by controlling its direction passing out of the plasma generation region.
- 15
- Embodiments of the present invention exploit this second approach and are aimed at ensuring that those charged particles that pass through the collector electrode (that is, the mesh of the electrostatic cage) do not deposit on the substrate the kinetic energy they have acquired through being accelerated in the electric field between the edge of
- 20 the plasma and the collector electrode. This is achieved by the parallel orientation of that electric field relative to the plane of the surface of the substrate being treated. Thus, for instance, energetic positive charge that leaks through the perforations in this arrangement cannot impact on the substrate without at least one collision with background gas, in which a significant fraction of energy and momentum may be
- 25 dispersed among many particles, thereby becoming less potent. At room temperature, the thermal kinetic energy of gas particles is approximately 0.03 eV. This is far less than the tens to hundreds of eV of kinetic energy their ions acquire when accelerated by the electric field at the edge of the plasma. Therefore (in the absence of significant magnetic fields) it is a good approximation to state that the total momentum of the charged
- 30 particles is directed parallel to the electric field lines. Thus, if we ensure that these field lines are parallel to the surface of the substrate being treated, the emergent charged particles from the plasma generator will be moving parallel to the substrate surface, and can only reach that surface by undergoing a collision with another gas particle.

However, these gas particles will themselves be at or about room temperature, and will therefore not deflect the charged particles much from their original trajectory. It is only after several collisions, each of which will reduce the kinetic energy of the charged particle, that it will be deflected sufficiently to enable it to reach the substrate surface.

5 By this time, the particle will essentially have lost all the extra kinetic energy it acquired through being accelerated in the electric field.

The physical arrangement described in the preferred embodiment ensures, by the orientation of all its electrodes perpendicular to the plane of the substrate surface, that  
10 the electric fields in the plasma generation region are parallel to that surface. This is in contrast to other arrangements of collector electrodes, where no account has been taken of the orientation of the electric field relative to the substrate. For example in a system having the electric field in the plasma perpendicular to the substrate surface, the flux of kinetic energy from charged particles is reduced only by a factor about equal to the  
15 proportion of charged particles collected by impact with the electrode. This will be comparable with the optical transparency of the said perforated electrode (often expressed simply as “% open area”).

It is also noteworthy that in our arrangement, the substrate is also afforded greater  
20 protection from the UV radiation that is produced in the plasma volume. This protection is a consequence of the greater separation and grazing incidence of any UV radiation in this arrangement, compared with the closer, perpendicular incidence that accompanies ‘in line’ (substrate parallel to perforated electrode) arrangements.

25 The embodiment shown in cross-section in Figure 2 maintains the space between the two wafers receiving simultaneous activation treatment clear of any solid objects. This provides the benefit of allowing wafers to be aligned to one another and bonded in-situ, without needing first to remove electrodes or other objects from the space between the wafers. Even in systems where a plasma is struck between the wafers and the wafers  
30 themselves act as the bounding electrodes for the plasma, it is not possible to align and bond the wafers until treatment has stopped, because as the wafers are brought together, the separation between them becomes too small to maintain the discharge. In contrast, the radical generator described here may be a self-contained unit independent of the



wafers, and can be allowed to operate continuously throughout the alignment and bonding operations. Apart from the benefit of a reduced overall process cycle time that this brings, it also offers the possibility of bonding wafers together on which chemical reactions whose products are very short-lived have been carried out using radicals generated by the apparatus.

The absence of solid objects in the space between the wafers also greatly reduces the likelihood of contaminating the surface of either wafer with particles. This is very important to wafer bonding. A rule of thumb for a standard 0.5 mm thick, 100 mm diameter silicon wafer is that a particle of a given diameter trapped between the wafers results in a zone that has failed to bond roughly 10,000 times larger in diameter.

The combination of pressure and optimum process duration for wafer activation allows the chosen geometry to be used effectively where the transport of radicals generated in the plasma volume to all parts of the wafer surface is by diffusion. At a pressure of approximately 100 Pa, and a processing time of 2 minutes (both typical in the use of this system) the mean diffusion length for the ozone molecule in oxygen is approximately 1.5 m. The distribution of the radicals generated by the apparatus is therefore highly uniform within the volume between the wafers, resulting in a correspondingly uniform activation of the wafer surface.

Further features of embodiments of the invention are described in the following clauses:

1. A method for a pre-bonding treatment to one or both surfaces by means of exposure to the active neutral species created locally by means of non-equilibrium electrical discharges so arranged as to substantially or totally exclude charged species from the treatment environment.
2. A method as in Clause 1 in which active neutral species are generated by a pulsed discharge having a duty-cycle in which excitation of the discharge is restricted to durations much shorter than the lifetimes of active neutral species.

3. A method as in Clause 1 in which active neutral species are generated remotely from the surface to be treated such that the diffusion distance for active neutral species is greater than the scale length of the surface, and charged species are substantially or totally excluded from the treatment environment by electrostatic means.

5

4. A method as in Clauses 1 and 3 in which charged species are substantially or totally excluded from the treatment environment by a combination of electrical and magnetic means.

10 5. A method as in Clauses 1 to 4 for the pre-treatment of semiconductor wafers and like materials to enable substantial reduction of the annealing temperature for direct bonding compared with that required for untreated surfaces.

15 6. A method as in Clauses 1 to 5 in which the active species are radical species formed from the fragmentation of molecular gases in the presence of one or more noble gases.

No doubt many other effective alternatives will occur to the skilled person. It will be understood that the invention is not limited to the described embodiments and  
20 encompasses modifications apparent to those skilled in the art lying within the spirit and scope of the claims appended hereto.

**CLAIMS:**

1. An apparatus for surface activation treatment of a substrate, the apparatus comprising:
  - first and second electrodes for generating a plasma, the electrodes defining a plasma generation region between the electrodes; and
  - mounting means for mounting a substrate substantially perpendicular to the electrodes;wherein at least one of said electrodes has perforations for allowing active neutral species generated, in use, in said plasma to diffuse to said substrate to treat said substrate, whilst restraining charged species of the said plasma.
2. An apparatus according to claim 1, wherein said first and second electrodes comprise substantially parallel planar electrodes.
3. An apparatus according to claim 1, wherein said first and second electrodes comprise substantially co-axial cylindrical electrodes.
4. An apparatus according to any one of claims 1 to 3, wherein said first and second electrodes further define an electric field in the vicinity of the electrodes, and wherein said electric field is substantially parallel to the said substrate.
5. An apparatus according to any one of claims 1 to 4, further comprising second mounting means for mounting a second substrate substantially parallel to the first substrate and substantially perpendicular to the electrodes, and means for bringing together said first and second substrates for bonding after said surface activation treatment.
6. A method for surface activation treatment and bonding of a pair of substrates, the method comprising:
  - mounting a first substrate substantially perpendicular to first and second electrodes, the electrodes defining a plasma generation region between the electrodes;
  - mounting a second substrate substantially parallel with said first substrate;

applying a potential between first and second electrodes to generate a plasma;  
and

bonding said first and second substrates by moving said substrates into contact with one another and applying pressure thereto;

wherein one of said electrodes has perforations for allowing active neutral species generated in the plasma to diffuse to the substrates to treat the substrates, whilst restraining direct impact from energetic, charged species of the plasma.

7. A method according to claim 6, wherein said first and second electrodes comprise a substantially concentric cylindrical shell.
8. A method for surface activation treatment of a substrate, the method comprising:  
applying a potential between first and second electrodes to generate a plasma between the electrodes, the electrodes defining a plasma generation region between the electrodes, said substrate being disposed outside said plasma generation region; and  
allowing active species generated in the plasma to diffuse to said substrate, to treat said substrate.
9. A method according to claim 8 wherein said potential is in the range 100V to 1000V, preferably 500V, more preferably 200V.
10. A method according to claim 8 or 9, wherein a duration of said applying is in the range 2 seconds to 600 seconds, preferably 240 seconds.
11. A method according to any one of claims 8 to 10, wherein said electrodes comprise annular electrodes.
12. A method according to any one of claims 8 to 10, wherein said electrodes comprise planar electrodes.
13. A method according to any one of claims 8 to 12, wherein said potential comprises a DC voltage.

14. A method according to any one of claims 8 to 12, wherein said potential comprises an AC voltage.
15. A method according to any one of claims 8 to 12, wherein said potential comprises a radio or microwave frequency potential, preferably an allowed science, technology and medicine (STM) frequency, more preferably 13.56MHz.
16. A method according to any one of claims 8 to 15, wherein a pressure of said surface activation treatment comprises a diffusive transport pressure, preferably in the range 10Pa to 1000Pa, more preferably 130Pa.
17. A method for surface activation treatment of a substrate, the method comprising:  
applying a potential between first and second electrodes to generate a plasma between the electrodes, the electrodes defining a plasma generation region between the electrodes, said substrate being disposed outside said plasma generation region, the electrodes defining an electrostatic cage perpendicular to said substrate to sandwich the plasma, the electrostatic cage having an inner mesh or other porous surface to allow active neutral species generated in the plasma to diffuse to said substrate, to treat said substrate whilst restraining energetic charged particles by electrostatic potentials and collisions.
18. An apparatus for surface activation treatment of a substrate, the apparatus comprising:  
first and second electrodes for generating a plasma, the electrodes defining a plasma generation region between the electrodes, said substrate being disposed outside said plasma generation region; and  
means for allowing active species generated in the plasma to diffuse to said substrate, to treat said substrate.
19. An apparatus according to claim 18, wherein said electrodes comprise annular electrodes.

20. An apparatus according to claim 18 or 19, wherein said means comprises a mesh in at least one of said electrodes.
21. An apparatus according to any one of claims 18 to 20, the apparatus being contained in a vessel for maintaining a pressure inside said vessel.
22. An apparatus according to any one of claims 18 to 21, wherein a diffusion distance of said active species is greater than a distance of said substrate from said plasma generation region.
23. An apparatus for surface activation treatment of a substrate, the apparatus comprising:  
first and second electrodes for generating a plasma, the electrodes defining a plasma generation region between the electrodes, wherein the said substrate, in use, is disposed outside said plasma generation region, the electrodes defining an electrostatic cage perpendicular to the said substrate to sandwich the plasma, said electrostatic cage having an inner mesh or other porous surface to allow active neutral species generated in the plasma to diffuse to said substrate, to treat said substrate whilst restraining charged particles by electrostatic potentials.
24. A method for applying a pre-bonding treatment to one or two surfaces of a substrate or pair of substrates by exposing to the active neutral species created locally by means of non-equilibrium electrical discharges so arranged as to substantially or totally exclude charged species from the treatment environment.
25. An apparatus for pre-bonding treatment of one or two surfaces of a substrate or pair of substrates, the apparatus comprising means for exposing said one or two surfaces to active neutral species created locally by means of non-equilibrium electrical discharges so arranged as to substantially or totally exclude charged species from the treatment environment.
26. A method for surface activation treatment of a substrate, the method comprising:  
generating a plasma in the vicinity of said substrate;

accelerating charged species in said plasma towards an electrode using an electric field such that they are encouraged to travel in a direction generally parallel to a surface of said substrate so that a majority of said charged species which escape said electric field travel past said surface without impacting on the substrate surface; and allowing neutral species in said plasma to diffuse onto said surface.

27. A method according to claim 26 wherein said accelerating comprises accelerating using an electric field in a direction substantially parallel to said substrate.

28. A method of surface activation treatment of a substrate surface, the method comprising:

generating a plasma in a vicinity of said substrate surface, wherein charged species of said plasma are accelerated in a direction parallel to the substrate surface such that the charged species are not accelerated towards the substrate surface by the field, and such that neutral species are free to diffuse onto said substrate surface.

29. An apparatus or method substantially as described herein with reference to the accompanying drawings.

**Application No:** GB0708109.4

**Examiner:** Dr Laura Starrs

**Claims searched:** 1-7, 17 and 23

**Date of search:** 7 September 2007

**Patents Act 1977: Search Report under Section 17**

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular relevance   |
|----------|--------------------|--|
| X,Y      | X: 1-4,<br>Y:5-7   | JP64001234 A<br>(MITSUBISHI) - see PAJ abstract in English and fig 3 |
| Y        | 5-7                | EP1518669 A2<br>(SUGA) - see figs 1-5 and paragraphs 18-36           |
| A        | --                 | JP58212129 A<br>(ANELVA) - see PAJ abstract in English and figures   |

**Categories:**

|   |   |   |  |
|---|---|---|--|
| X | Document indicating lack of novelty or inventive step   | A | Document indicating technological background and/or state of the art.  |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention           |
| & | Member of the same patent family  | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |

**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>X</sup>:

Worldwide search of patent documents classified in the following areas of the IPC

C23C; H01J; H01L

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

**International Classification:**

| Subclass | Subgroup | Valid From |
|----------|----------|------------|
| H01J     | 0037/32  | 01/01/2006 |
| H01L     | 0021/302 | 01/01/2006 |
| H01L     | 0021/306 | 01/01/2006 |