



ELASTOMER BONDED PARTS FOR PLASMA PROCESSES AND METHOD FOR MANUFACTURE AND USE THEREOF

BACKGROUND OF THE INVENTION



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Field of the Invention

The invention relates to an apparatus for plasma processing of
5 semiconductor substrates such as semiconductor wafers.

Description of the Related Art

Electrodes used in plasma processing reactors for processing semiconductor
substrates such as silicon wafers are disclosed in U.S. Patent Nos. 5,074,456 and
10 5,569,356, the disclosures of which are hereby incorporated by reference. The
'456 patent discloses an electrode assembly for a parallel plate reactor apparatus
wherein the upper electrode is of semiconductor purity and bonded to a support
frame by adhesive, solder, or brazing layer. The soldering or brazing layer can be
low vapor pressure metals such as indium, silver and alloys thereof and the bonded
15 surfaces of the support frame and the electrode can be coated with a thin layer of
metal such as titanium or nickel to promote wetability and adhesion of the bonding
layer. It has been found that metallurgical bonds such as In bonds cause the
electrode to warp due to differential thermal expansion/contraction of the electrode
and the part to which the electrode is bonded. It has also been found that these
20 metallurgical bonds fail at high plasma processing powers due to thermal fatigue
and/or melting of the bond.

Dry plasma etching, reactive ion etching, and ion milling techniques were
developed in order to overcome numerous limitations associated with chemical

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etching of semiconductor wafers. Plasma etching, in particular, allows the vertical etch rate to be made much greater than the horizontal etch rate so that the resulting aspect ratio (i.e., the height to width ratio of the resulting notch) of the etched features can be adequately controlled. In fact, plasma etching enables very fine features with high aspect ratios to be formed in films over 1 micrometer in thickness.

During the plasma etching process, a plasma is formed above the masked surface of the wafer by adding large amounts of energy to a gas at relatively low pressure, resulting in ionizing the gas. By adjusting the electrical potential of the substrate to be etched, charged species in the plasma can be directed to impinge substantially normally upon the wafer, wherein materials in the unmasked regions of the wafer are removed.

The etching process can often be made more effective by using gases that are chemically reactive with the material being etched. So called "reactive ion etching" combines the energetic etching effects of the plasma with the chemical etching effect of the gas. However, many chemically active agents have been found to cause excessive electrode wear.

It is desirable to evenly distribute the plasma over the surface of the wafer in order to obtain uniform etching rates over the entire surface of the wafer. For example, U.S. Patent Nos. 4,595,484, 4,792,378, 4,820,371, 4,960,488 disclose showerhead electrodes for distributing gas through a number of holes in the electrodes. These patents generally describe gas distribution plates having an

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arrangement of apertures tailored to provide a uniform flow of gas vapors to a semiconductor wafer.

A reactive ion etching system typically consists of an etching chamber with an upper electrode or anode and a lower electrode or cathode positioned therein.

5 The cathode is negatively biased with respect to the anode and the container walls.

The wafer to be etched is covered by a suitable mask and placed directly on the cathode. A chemically reactive gas such as CF_4 , CHF_3 , CClF_3 and SF_6 or mixtures thereof with O_2 , N_2 , He or Ar is introduced into the etching chamber and

maintained at a pressure which is typically in the millitorr range. The upper

10 electrode is provided with gas holes which permit the gas to be uniformly dispersed

through the electrode into the chamber. The electric field established between the

anode and the cathode will dissociate the reactive gas forming a plasma. The

surface of the wafer is etched by chemical interaction with the active ions and by

momentum transfer of the ions striking the surface of the wafer. The electric field

15 created by the electrodes will attract the ions to the cathode, causing the ions to

strike the surface in a predominantly vertical direction so that the process produces

well-defined vertically etched side walls.

A showerhead electrode 10 in an assembly for a single wafer etcher is

shown in FIG. 1. Such a showerhead electrode 10 is typically used with an

20 electrostatic chuck having a flat bottom electrode on which a wafer is supported

spaced 1 to 2 cm below the electrode 10. Such chucking arrangements provide

temperature control of the wafer by supplying backside He pressure which controls

the rate of heat transfer between the wafer and the chuck.

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The electrode assembly is a consumable part which must be replaced periodically. Because the electrode assembly is attached to a temperature-controlled member, for ease of replacement, it has been conventional to metallurgically bond the upper surface of the outer edge of the silicon electrode 10 to a graphite support ring 12 with indium which has a melting point of about 156 °C. Such a low melting point limits the amount of RF power which can be applied to the electrode since the RF power absorbed by the plasma causes the electrode to heat up. The electrode 10 is a planar disk having uniform thickness from center to edge thereof. An outer flange on ring 12 is clamped by an aluminum clamping ring 16 to an aluminum temperature-controlled member 14 having water cooling channels 13. Water is circulated in the cooling channels 13 by water inlet/outlet connections 13a. A plasma confinement ring 17 comprised of a stack of spaced-apart quartz rings surrounds the outer periphery of electrode 10. The plasma confinement ring 17 is bolted to a dielectric annular ring 18 which in turn is bolted to a dielectric housing 18a. The purpose and function of confinement ring 17 is to cause a pressure differential in the reactor and increase the electrical resistance between the reaction chamber walls and the plasma thereby confining the plasma between the upper and lower electrodes. A radially inwardly extending flange of clamping ring 16 engages the outer flange of graphite support ring 12. Thus, no clamping pressure is applied directly against the exposed surface of electrode 10.

Process gas from a gas supply is supplied to electrode 10 through a central hole 20 in the temperature-controlled member 14. The gas then is distributed through one or more vertically spaced apart baffle plates 22 and passes through gas

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distribution holes (not shown) in the electrode 10 to evenly disperse the process gas into reaction chamber 24. In order to provide enhanced heat conduction from electrode 10 to temperature-controlled member 14, process gas can be supplied to fill open spaces between opposed surfaces of temperature-controlled member 14 and support ring 12. In addition, gas passage 27 connected to a gas passage (not shown) in the annular ring 18 or confinement ring 17 allows pressure to be monitored in the reaction chamber 24. To maintain process gas under pressure between temperature-controlled member 14 and support ring 12, a first O-ring seal 28 is provided between an inner surface of support ring 12 and an opposed surface of temperature-controlled member 14 and a second O-ring seal 29 is provided between an outer part of an upper surface of support ring 12 and an opposed surface of member 14. In order to maintain the vacuum environment in chamber 24, additional O-rings 30, 32 are provided between temperature-controlled member 14 and cylindrical member 18b and between cylindrical member 18b and housing 18a.

The process of bonding the silicon electrode 10 to the support ring 12 requires heating of the electrode to a bonding temperature which may cause bowing or cracking of the electrode due to the different thermal coefficients of expansion of the silicon electrode 10 and the graphite ring 12. Also, contamination of wafers could result from solder particles or vaporized solder contaminants deriving from the joint between electrode 10 and ring 12 or from the ring itself. During high-power plasma processing, the temperature of the electrode may even become high enough to melt the solder and cause part or all of the electrode 10 to separate from the ring 12. However, even if the electrode 10 becomes partly separated from ring

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12, local variations in electrical and thermal power transmission between ring 12 and electrode 10 could result in nonuniform plasma density beneath the electrode 10.

In the field of semiconductor processing, vacuum processing chambers are generally used for etching and chemical vapor deposition (CVD) of materials on substrates by supplying an etching or deposition gas to the vacuum chamber and application of an RF field to the gas to energize the gas into a plasma state.

Examples of parallel plate, transformer coupled plasma (TCP™) which is also called inductively coupled plasma (ICP), and electron-cyclotron resonance (ECR) reactors and components thereof are disclosed in commonly owned U.S. Patent Nos. 4,340,462; 4,948,458; 5,200,232 and 5,820,723. Because of the corrosive nature of the plasma environment in such reactors and the requirement for minimizing particle and/or heavy metal contamination, it is highly desirable for the components of such equipment to exhibit high corrosion resistance.

During processing of semiconductor substrates, the substrates are typically held in place within the vacuum chamber on substrate holders by mechanical clamps and electrostatic clamps (ESC). Examples of such clamping systems and components thereof can be found in commonly owned U.S. Patent Nos. 5,262,029 and 5,838,529. Process gas can be supplied to the chamber in various ways such as by gas nozzles, gas rings, gas distribution plates, etc. An example of a temperature controlled gas distribution plate for an inductively coupled plasma reactor and components thereof can be found in commonly owned U.S. Patent No. 5,863,376.

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Aluminum and aluminum alloys are commonly used for walls of plasma reactors. In order to prevent corrosion of the walls, various techniques have been proposed for coating the aluminum surface with various coatings. For instance, U.S. Patent No. 5,641,375 discloses that aluminum chamber walls have been anodized to reduce plasma erosion and wear of the walls. The '375 patent states that eventually the anodized layer is sputtered or etched off and the chamber must be replaced. U.S. Patent No. 5,680,013 states that a technique for flame spraying Al_2O_3 on metal surfaces of an etching chamber is disclosed in U.S. Patent No. 4,491,496. The '013 patent states that the differences in thermal expansion coefficients between aluminum and ceramic coatings such as aluminum oxide leads to cracking of the coatings due to thermal cycling and eventual failure of the coatings in corrosive environments. U.S. Patent No. 5,085,727 discloses a carbon coating for walls of a plasma chamber wherein the coating is deposited by plasma assisted CVD..

In order to protect the chamber walls, U.S. Patent Nos. 5,366,585; 5,556,501; 5,788,799; 5,798,016; and 5,885,356 propose liner arrangements. For instance, the '585 patent discloses a free standing ceramic liner having a thickness of at least 0.005 inches and machined from solid alumina. The '585 patent also mentions use of ceramic layers which are deposited without consuming the underlying aluminum can be provided by flame sprayed or plasma sprayed aluminum oxide. The '501 patent discloses a process-compatible liner of polymer or quartz or ceramic. The '799 patent discloses a temperature controlled ceramic liner having a resistance heater embedded therein and the ceramic can be alumina,

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silica, titania, zirconia, silicon carbide, titanium carbide, zirconium carbide, aluminum nitride, boron nitride, silicon nitride and titanium nitride. The '016 patent discloses a liner of ceramics, aluminum, steel and/or quartz with aluminum being preferred for its ease of machinability and having a coating of aluminum oxide, Sc_2O_3 or Y_2O_3 , with Al_2O_3 being preferred for coating aluminum to provide protection of the aluminum from plasma. The '356 patent discloses a ceramic liner of alumina and a ceramic shield of aluminum nitride for the wafer pedestal for use in CVD chambers. U.S. Patent No. 5,904,778 discloses a SiC CVD coating on free standing SiC for use as a chamber wall, chamber roof, or collar around the wafer. U.S. Patent No. 5,292,399 discloses a SiC ring surrounding a wafer pedestal. A technique for preparing sintered SiC is disclosed in U.S. Patent No. 5,182,059.

With regard to plasma reactor components such as showerhead gas distribution systems, various proposals have been made with respect to the materials of the showerheads. For instance, commonly owned U.S. Patent No. 5,569,356 discloses a showerhead of silicon, graphite, or silicon carbide. U.S. Patent No. 5,888,907 discloses a showerhead electrode of amorphous carbon, SiC or Al. U.S. Patent Nos. 5,006,220 and 5,022,979 disclose a showerhead electrode either made entirely of SiC or a base of carbon coated with SiC deposited by CVD to provide a surface layer of highly pure SiC.

In view of the need for high purity and corrosion resistance for components of semiconductor processing equipment, there is a need in the art for improvements in materials and/or coatings used for such components. Moreover, with regard to

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the chamber materials, any materials which can increase the service life of a plasma reactor chamber and thus reduce the down time of the apparatus, would be beneficial in reducing the cost of processing the semiconductor wafers.

SUMMARY OF THE INVENTION

The invention provides an elastomeric joint assembly of parts in a plasma reaction chamber used in semiconductor substrate processing. The parts include components of substrate supports, gas distribution systems, liners, electrodes, windows, temperature controlled surfaces, and the like. The elastomeric joint assembly comprises a first part having a bonding surface, a second part having a bonding surface engaging the bonding surface of the first part; and an elastomeric joint between the first part and the second part, the elastomeric joint resiliently attaching the first part to the second part so as to allow movement between the first part and the second part during temperature cycling thereof.

The elastomeric joint can comprise a polymeric material compatible with a vacuum environment and resistant to thermal gradation at temperatures of up to and including 200°C. The elastomeric joint can include a polymeric material and a filler of electrically and/or thermally conductive particles. The polymeric material can comprise polyimide, polyketone, polyetherketone, polyether sulfone, polyethylene terephthalate, fluoroethylene propylene copolymers, cellulose, triacetates or silicone. The filler can be metal particles such as an aluminum alloy having 5 to 20 weight % silicon. The elastomeric joint can be located between

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mating surfaces which are contoured to provide an interlocking and/or self-aligning arrangement.

According to one embodiment, the invention provides an electrode assembly for use in a plasma reaction chamber for semiconductor substrate processing. The electrode assembly includes a support member having a bonding surface, an RF driven electrode and an elastomeric joint therebetween. The electrode has an exposed surface which is intended to face the semiconductor substrate to be processed in the reaction chamber and a bonding surface at an outer edge of the electrode joined to the bonding surface of the support member by the elastomeric joint. The elastomeric joint compensates for thermal mismatch and/or thermal gradients since it allows the electrode to move relative to the support member during temperature cycling of the assembly.

According to a preferred embodiment, the electrode comprises a showerhead electrode and the electrode assembly is removably attached to a temperature-controlled member having a gas passage supplying a process gas to a backside of the showerhead electrode. In this case, the temperature-controlled member optionally can include a cavity and one or more baffle plates located in the cavity whereby the gas passage supplies process gas into the cavity to pass through the baffles and outlets of the showerhead electrode. A recess can be located in the electrode and/or the support member so as to accommodate the elastomeric joint and provide a seal which extends completely around the outer edge of the electrode. The electrode can comprise a circular silicon disk of uniform or nonuniform thickness and the elastomeric joint can comprise an electrically conductive material

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having an electrically conductive filler such as metal particles. The filler preferably provides direct electrical contact between the electrode and the support member.

The invention also provides a method of assembling an RF powered electrode such as a showerhead electrode useful in a plasma reaction chamber. The method includes applying an elastomeric bonding material to one or more mating surfaces of the electrode and a support member, assembling the electrode and support member and curing the bonding material to form an elastomeric joint between the electrode and support member. The mating surfaces are preferably coated with a primer which is subsequently cured and/or the bonding material is subjected to a densifying step in a vacuum environment to remove gas bubbles prior to being applied to the electrode and/or the support member. In a preferred embodiment, the elastomeric bonding material is applied to a shallow recess in a graphite support ring and a silicon electrode is pressed against the support ring during curing of the joint.

The invention also provides a method of processing a semiconductor substrate in a plasma reaction chamber. The method includes supplying a semiconductor substrate such as a wafer to the plasma reaction chamber, supplying process gas to the chamber, and processing the substrate by supplying electrical power to an electrode assembly. The electrode assembly includes an electrode and a support member and the electrical power passes to the electrode through an elastomeric joint which bonds the electrode to the support member such that the electrode moves relative to the support member during temperature cycling of the assembly. The electrode can be a showerhead electrode and the process gas can be

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supplied to the chamber through a gas passage in a temperature-controlled member mounted in the plasma reaction chamber such that the process gas passes through an exposed surface of the showerhead electrode. The support member can be a graphite ring removably attached to the temperature-controlled member and the electrode can be a silicon disc joined to the graphite ring solely by the elastomeric joint.

The invention provides a plasma processing system for processing semiconductor substrates including a plasma chamber, a substrate support, a gas supply, an energy source, a ceramic liner and a resilient support member. The plasma processing chamber has an interior space bounded by a chamber sidewall and the substrate support on which a substrate is processed is located within the interior space. The chamber sidewall is spaced outwardly of a periphery of the substrate support and the gas supply supplies process gas to the interior space. The energy source energizes the process gas in the interior space into a plasma state during processing of the substrate. The ceramic liner is supported between the chamber sidewall and the periphery of the substrate support by the resilient support member.

According to a preferred embodiment, the resilient support member comprises an elastomeric joint or an elastically bendable metal frame and the ceramic member comprises a one-piece ceramic liner or an assembly of ceramic tiles. For instance, the ceramic member can comprise an assembly of ceramic tiles and metal backing members and the resilient support can comprise an elastomeric joint which attaches each of the ceramic tiles to a respective one of the metal

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backing members. The metal backing members can be supported on an elastically bendable metal frame supported by a thermally controlled member such that heat can be withdrawn from the ceramic tiles via a thermal path which extends through the elastomeric joint, the metal backing members and the bendable metal frame to the thermally controlled member. Alternatively, the ceramic member can comprise an assembly of ceramic tiles and the resilient support can comprise an elastomeric joint between each of the ceramic tiles and the chamber sidewall.

According to another embodiment, a heater is supported by the bendable metal frame such that the heater can heat the ceramic member. The resilient support member can comprise an elastically bendable metal frame which includes an inner frame member and an outer frame member. The resilient support member can further comprise an elastomeric joint between the ceramic member and the inner frame member, the inner frame member being supported by the outer frame member, the outer frame member being supported by the chamber, and the tiles being a series of interlocked ceramic tiles. Preferably, the ceramic member comprises a one-piece SiC liner or a plurality of SiC tiles.

The resilient member can comprise inner and outer metal frame members configured to allow differential thermal stresses on the ceramic member and the frame members to be accommodated during operation of the plasma processing system. In such an arrangement, an upper portion of the outer frame member can be supported by a thermally controlled part of the chamber, a lower portion of the outer frame member can be attached to a lower portion of the inner frame member, and the ceramic member can be supported by the inner frame member. Further, the

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bendable metal frame can include a continuous upper portion and a segmented lower portion. For instance, the bendable metal frame can be cylindrical and the segmented lower portion can comprise axially extending segments separated from each other by axially extending slots. If the inner and outer metal frame members are cylindrical and include continuous upper portions and segmented lower portions, the segmented lower portions comprise axially extending segments separated from each other by axially extending slots.

According to another embodiment of the invention, the liner further includes a ceramic plasma screen extending inwardly from a lower portion of the ceramic member, the ceramic plasma screen including passages through which process gas and reaction byproducts are removed from the interior of the chamber during processing of a substrate. For instance, the ceramic plasma screen can comprise a plurality of segments supported in an annular space between the chamber sidewall and the substrate support, the passages comprising slots extending radially inwardly from the chamber sidewall. The ceramic plasma screen can be attached to the resilient support member by an electrically conductive elastomeric joint, the resilient support member comprising a bendable metal frame and the plasma screen being electrically grounded to the bendable metal frame by the elastomeric joint.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be further described with reference to the figures, wherein:

FIG. 1 is a side sectional view of a prior art showerhead electrode assembly for single wafer processing;

FIG. 2 is a side sectional view of a showerhead electrode assembly according to one embodiment of the present invention; and

FIG. 3 is a side sectional view of a portion of the arrangement shown in FIG. 2.

FIG. 4 shows a plasma reaction chamber in accordance with an embodiment of the invention wherein a ceramic liner supported on a resilient frame surrounds a substrate support;

FIG. 5 shows the plasma reaction chamber of FIG. 4 without various components including the liner;

FIG. 6 shows a plasma reaction chamber in accordance with an embodiment of the invention wherein the ceramic liner comprises a series of tiles mounted on backing plates;

FIG. 7 shows a perspective view of the plasma reaction chamber of FIG. 6;

FIG. 8 shows details of a wafer introducing slot in the plasma reaction chamber of FIG. 6;

FIG. 9 shows how the edges of the tiles of FIG. 6 fit together in an interlocking arrangement;

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FIG. 10 shows details of an elastically bendable frame for supporting a continuous cylindrical ceramic liner in accordance with a fourth embodiment of the invention;

FIG. 11 shows details of a segmented metal frame attached to a lower edge of the cylindrical liner of FIG. 10; and

FIG. 12 is a graph showing temperatures of the heater flange, tile and lower flange of the arrangement shown in Figure 3 over the course of a 200 wafer run.

DETAILED DESCRIPTION OF THE INVENTION

The electrode assembly of the invention overcomes disadvantages of the prior art electrode assembly shown in FIG. 1 by providing better accommodation of stresses due to thermal mismatch between the electrode and support member which prolongs the life of the electrode, allowing the electrode to be exposed to higher temperatures which allows the reactor to be run at higher power, lowering the cost of production and assembly of the electrode, and providing a greater degree of flatness from the center to the outer periphery of the electrode during operation of the reactor which allows uniform plasma processing of semiconductor substrates. The plasma processing includes etching of materials such as oxide layers, stripping of materials such as photoresists, deposition of layers such as SiO_2 , etc. The primary benefits of the invention, however, are the reduction in stress in the electrode assembly due to mismatch of coefficients of thermal expansion and/or thermal gradients of the electrode components and allowing higher power operation of the plasma reactor.

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A showerhead electrode assembly according to the present invention includes an electrode, a support member, and an elastomeric joint for resiliently bonding the electrode to the support member. Thus, the invention avoids the need for solder bonding the electrode to a supporting ring which can lead to the various disadvantages discussed above with respect to the arrangement shown in FIG. 1.

Because the electrode assembly is a consumable part which must be periodically replaced, the electrode is preferably bonded to a support member in the form of a ring which can be mechanically clamped to a permanent part of the reactor. For instance, the ring of the electrode assembly can be removably attached to a temperature-controlled member having a gas passage for providing process gas (e.g., a suitable plasma etching gas for etching silicon dioxide or other layer of material on the wafer) which passes into a cavity containing baffle plates and outwardly through outlets in the electrode. If desired, however, the electrode assembly can have other arrangements wherein the electrode is not a showerhead electrode and/or the support member is not in the form of a ring. For instance, the electrode could be a showerhead electrode bonded to a backing plate having gas distribution holes communicating with those in the electrode. Another possibility is where the electrode is bonded to a support member in the form of a plate, cylinder, projections on a base member, etc.

According to the preferred embodiment of the invention, the support member is in the form of a ring having a radially outwardly extending flange at one edge thereof for removably attaching the electrode assembly to a temperature-controlled member located in the interior of a plasma reaction chamber such as the

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type used for single wafer plasma etching. In the assembled condition, cooling channels in the upper surface of the temperature-controlled member can provide water cooling of the electrode assembly.

The electrode preferably consists of an electrically conductive material such as a planar silicon (e.g., single crystal silicon), graphite or silicon carbide electrode disc having uniform thickness from the center to the outer edge thereof. However, electrodes having nonuniform thickness, different materials and/or without process gas distribution holes could also be used with the electrode assembly according to the invention. In a preferred embodiment, the electrode is a showerhead electrode provided with a plurality of spaced apart gas discharge passages which are of a size and distribution suitable for supplying a process gas which is energized by the electrode and forms a plasma in the reaction chamber beneath the electrode. However, any type of electrode useful in a plasma reactor or vacuum environment can be used as part of the electrode assembly according to the invention, such electrodes including sputter electrodes.

The elastomeric joint can comprise any suitable elastomeric material such as a polymer material compatible with a vacuum environment and resistant to thermal degradation at high temperatures such as above 200°C. The elastomer material can optionally include a filler of electrically and/or thermally conductive particles or other shaped filler such as wire mesh, woven or non-woven conductive fabric, etc. Polymeric materials which can be used in plasma environments above 160°C include polyimide, polyketone, polyetherketone, polyether sulfone, polyethylene terephthalate, fluoroethylene propylene copolymers, cellulose, triacetates, silicone,

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and rubber. Examples of high purity elastomeric materials include one-component room temperature curing adhesives available from General Electric as RTV 133 and RTV 167, a one-component flowable heat-curable (e.g. over 100°C) adhesive available from General Electric as TSE 3221, and a two-part addition cure elastomer available from Dow Corning as "SILASTIC." An especially preferred elastomer is a polydimethylsiloxane containing elastomer such as a catalyst cured, e.g. Pt-cured, elastomer available from Rhodia as V217, an elastomer stable at temperatures of 250°C and higher.

In the case where the elastomer is an electrically conductive elastomer, the electrically conductive filler material can comprise particles of a an electrically conductive metal or metal alloy. A preferred metal for use in the impurity sensitive environment of a plasma reaction chamber is an aluminum alloy such as a 5-20 weight % silicon containing aluminum base alloy. For example, the aluminum alloy can include about 15 wt % silicon.

In order to stay within the elastic limits of the finally formed joint, it has been found useful to provide one or more recesses in at least one of the members to be attached. That is, too thin of a joint could tear during thermal cycling whereas too thick a joint could affect electrical power transmission and/or thermal coupling between the parts to be joined. In the case of attaching a silicon electrode to a graphite support ring, a recess can be provided in the graphite ring for purposes of maintaining a thin enough layer of elastomer between the electrode and support ring to provide adequate electrical coupling yet thick enough to accommodate thermal mismatch between the electrode and support ring. As an example, in the case of a

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thermally conductive elastomer having a filler content of about 45 to 55 volume % and an average filler particle size of 0.7 to 2 μm , the recess can have a depth of about 2 mils (about 50 μm). In contact areas surrounding the recess, the elastomer is thin enough to provide higher electrical conductivity than exhibited by the bulk elastomer because individual particles bridge the opposed contact surfaces. In addition, the combination of suitably sized particles and groove depth allows the passage of RF current through the joint. If the filler content is increased to above 65 to 70 volume % for providing a better DC path through the joint, such high filler contents could adversely affect the elasticity of the joint. However, it is not necessary to use an electrically and/or thermally conductive elastomer since sufficient RF power can be supplied to the electrode through a thin area of the elastomeric joint due to capacitive coupling between the electrode and the support member. Such a thin joint also provides adequate thermal conductivity between the electrode and the support member.

The mating surfaces of the electrode and support member can be planar or non-planar. For instance, one mating surface can be planar and the other can include a recess for receiving the bonding material as described above. Alternatively, the mating surfaces can be contoured to provide an interlocking and/or self-aligning arrangement. In order to enhance adhesion of the elastomeric bonding material, the mating surfaces are preferably coated with a suitable primer. If the bonding material is the V217 material described above, the primer can be a siloxane in an aliphatic solvent such as Rhodia's VI-SIL V-06C.

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The primer can be applied as a thin coating by any suitable technique such as wiping, brushing, spraying, etc. to create bonding sites on the mating surfaces for the later applied bonding material. If the primer contains a solvent, application of the primer by wiping can enhance bonding by cleaning the mating surfaces. A siloxane containing primer reacts with air and creates Si bonding sites when cured in air at room temperature. Such primers provide a visual indication of the amount of bonding sites with excessive primer locations appearing powdery. Although the primer provides an easy and effective technique for conditioning the mating surfaces, other conditioning techniques such as treating the surfaces in an oxygen plasma can be used.

In order to provide a good quality elastomeric joint, it is desirable to densify the elastomer bonding material prior to applying it to the mating surfaces. For example, the elastomer bonding material can be subjected to vibration in a vacuum environment at ambient or elevated temperature. A vacuum pressure below 1 Torr, preferably below 500 mTorr can be used to degas the bonding material. The vacuum can be pulsed by venting one or more times during the densifying treatment to enhance breakup of bubbles generated by the vacuum. As an example, a vacuum of about 200 mTorr can be pulsed 4 or 5 times over a 30 minute period of time. The presence of filler in the elastomeric bonding material also aids in breaking up the bubbles formed in the vacuum. Without the agitation/pulsed vacuum, the elastomer bonding material expands under vacuum to about 10 times its starting volume, thus creating storage and cleanup problems which can introduce new air

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pockets into the material. Such gas sites could form bubbles during curing of the bonding material, thus degrading the finally formed joint.

Masking of the mating surfaces provides a useful way of protecting the surrounding surfaces and removing excess bonding material after the joint is formed. For the highly pure materials used as components of plasma reactors, polyester and/or polyimide materials such as MYLAR and KAPTON tapes having silicon/graphite compatible adhesive can be used. In the case of a silicon showerhead electrode, it is desirable to cover the gas outlets on the electrode with MYLAR tape and the outside edge of the electrode can be covered with a strip of KAPTON tape. In the case of a graphite support ring, the inner and outer edges can be covered with strips of KAPTON tape. In order to aid removal of excess bonding material after the joint is formed, it is useful to apply primer to the masking material to promote sticking of the elastomer bonding material thereto. In this way, when the masking material is removed from the bonded parts, the excess bonding material adhered to the masking material is also removed.

The elastomeric bonding material can be applied to one or both of the mating surfaces. In the case of a silicon electrode and graphite support ring, it is desirable to apply the bonding material to the graphite support ring because it is more porous. For example, a bead of the bonding material can be applied into a recess extending completely around the support ring. The amount of the bonding material preferably exceeds the volume of the finally formed joint. As an example, the bonding material can be applied in an amount of about 5 times the amount needed to form the joint.

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After the bonding material is applied to at least one of the mating surfaces, the bonding material can be subjected to a densifying step. For instance, the graphite ring with the bonding material applied thereto can be placed in a vacuum environment as described earlier to remove gas bubbles introduced during the step of applying the bonding material.

After the bonding material is applied to at least one of the mating surfaces, the parts can be assembled such that the mating surfaces are pressed together. In the case of the electrode and support ring described above, the electrode can be held in a fixture and plastic pins of the fixture can be used to guide the support ring into precise contact with the electrode. Initially, slight pressure such as hand pressure can be used to spread the elastomer throughout the joint to be formed. After the elastomer is spread, a static load such as a 30 pound weight can be applied to the electrode during curing of the bond.

The bond can be cured at ambient or elevated temperature in an atmospheric or protective gas environment. For example, the assembly can be placed in a convection oven and heated to a low temperature to accelerate curing of the bond without inducing thermal strains into the parts to be joined. In the case of the electrode and support ring described above, it is desirable to maintain the temperature below 60 °C, e.g. 45 to 50 °C for a suitable time, e.g. 3 to 5 hours.

After the bond is cured to form the elastomeric joint, the assembly is cooled and the masking material is removed. Further, any additional cleanup and/or further manufacturing steps such as outgassing in a vacuum oven can be carried out depending on the requirements of the assembly operation.

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FIG. 2 shows a showerhead electrode arrangement 40 in accordance with one embodiment of the invention. The electrode arrangement 40 includes an electrode 42 and an electrically conductive support ring 44. The electrode assembly can be substituted for the electrode assembly constituted by electrode 10 and support ring 12 shown in FIG. 1. The electrode 40 differs from the In-bonded assembly shown in Figure 1 in that the electrode 42 is bonded to the support ring 44 by an elastomeric joint 46 which can be located in a recess 48, as shown in FIG. 3.

In accordance with an embodiment of the invention, the recess 48 extends continuously around the support ring 44 between an inner wall (not shown) and an outer wall 50 of the support ring 44. Each wall 50 can be as thin as possible, e.g. about 30 mils wide, which allows the elastomer to form a thin layer (e.g. about $2\mu\text{m}$ thick in the case where the elastomer includes 0.7 to $2\mu\text{m}$ sized filler) in the area in contact with each wall 50 and a thicker layer (e.g. about 0.0025 inch) in the recess 48. The recess formed by the walls can be extremely shallow, e.g. about 2 mils deep, which provides a very thin elastomeric joint having enough strength to adhesively bond the electrode to the support ring yet allow movement of the electrode relative to the support ring during temperature cycling of the electrode assembly. Additionally, the walls of the recess can protect the elastomeric joint from attack by the plasma environment in the reactor.

The electrode assembly dimensions can be adapted to meet the demands of the intended use of the electrode assembly. As an example, if the electrode is used to process an 8 inch wafer, the electrode can have a diameter slightly less than 9 inches and the support ring can have a width at the interface between the electrode

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and the support ring slightly less than 0.5 inch. For example, the support ring at the interface can have an inner diameter of 8 inches and an outer diameter at the interface of 8.8 inches. In such a case, the interface between the electrode and support ring can have a width of about 0.4 inch and the recess can have a width of 0.34 inch if the walls are 0.030 inch wide.

While a specific example of a joint has been described, other elastomeric joints can be utilized to attach the electrode to a support member in the form of a support ring or other configuration provided that the joint has sufficient strength under the elevated temperature and plasma conditions experienced in a plasma reactor environment. The elastomeric joint preferably is vacuum compatible, has sufficient toughness, tear strength, elasticity, resistance to thermal degradation, thermal conductivity and/or electrical conductivity. In the case where the electrode is a showerhead electrode, the elastomeric joint must be able to withstand the weight of the electrode and gas pressure of the process gas supplied to the showerhead electrode.

According to the invention, use of an elastomer material to attach the electrode to the support ring offers advantages compared to indium bonded electrodes with respect to reduced likelihood of breakage of electrode, reduced likelihood of debonding of electrode from support ring due to thermal fatigue, reduced distortion and thus improved thermal contact between the support ring and the temperature-controlled member during temperature cycling of the electrode assembly, improved electrical power supply to the electrode by maintaining good capacitive coupling/electrical contact between electrode and support ring, reduced

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chamber contamination from particles or impurities and/or increased power capability due to the ability of the electrode assembly to withstand higher temperatures.

The apparatus according to the invention is useful for wafer processing such as plasma etching, deposition, etc., in multiple or single wafer processing. For instance, the apparatus can be used for etching or depositing BPSG, oxides such as thermal silicon dioxide or pyrolytic oxides and photoresist materials. The apparatus can maintain desirable levels of submicron contact profile, CDs and low particle contamination. With respect to etching BPSG, etch rates of about 8000 Å/min can be achieved and etch uniformity can be maintained at around 4% for electrode lifetimes of greater than 30,000 RF minutes, whereas In-bonded electrode assemblies may require replacement as early as 2400 RF minutes. Photoresist etch rates of about 800 Å/min can be maintained while etching silicon dioxide at about 6000 Å/min. With respect to CD line measurement, measurements by SEM of wafers etched for 200 seconds to provide vias in silicon dioxide can provide center and edge CDs less than 0.02 μm .

According to another embodiment of the invention, a ceramic liner is provided which can achieve one or more of the following objectives: maintaining good plasma formation by providing an electrical path to ground through the liner, avoiding process drift by providing thermal control of the liner, overcoming differential thermal expansion between ceramic and metal components by providing a resilient liner support, and preventing Al contamination by shielding Al chamber walls and components from the substrate being processed. With regard to the

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electrical grounding of the liner, the ceramic liner is made from an electrically conductive material. A preferred ceramic material is Si or SiC, materials which can be obtained in high purity and which have been found to exhibit high resistance to the corrosive conditions found in plasma reactors such as plasma etching chambers.

The invention provides a plasma chamber wherein various components including a ceramic liner are made of Si or SiC. Such materials are compatible in plasma environments since plasma erosion of Si or SiC produces gaseous Si or C compounds which can be pumped from the chamber without particle contamination of the substrate. With regard to thermal control, SiC has been found to exhibit exceptionally high thermal conductivity enabling the liner to be heated or cooled to a desired temperature range during processing of substrates such as silicon wafers. With regard to overcoming differential expansion, the resilient support according to the invention is designed to allow the ceramic liner to freely expand or contract within the chamber. With regard to preventing Al contamination, the ceramic liner confines the plasma inwardly of the liner and thus avoids attack of Al walls or components by the plasma.

A vacuum processing chamber according to the present invention may be used for various semiconductor plasma processing steps such as etching, deposition, resist stripping, etc. An example of a vacuum processing chamber 2 having an inductively coupled plasma source is shown in FIG. 4 wherein processing gas is supplied to the processing chamber 2 by suitable apparatus such as gas distribution rings, gas distribution plate, injection nozzles, etc., and a vacuum is maintained in the interior 4 of the chamber by suitable vacuum pump apparatus. The substrate to

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be processed in the chamber can comprise a silicon semiconductor wafer 6 supported on a substrate support 8. The substrate support 8 can include an electrostatic chuck and a focus ring 10. The vacuum pump can be connected to a large outlet port 12 in an endwall such as the bottom of process chamber. The vacuum processing chamber can include a dielectric window 14, a gas distribution plate 16 and RF power can be supplied to the chamber through an external RF antenna such as a planar coil 18 outside the dielectric window 14 on an endwall such as the top of the chamber. However, the plasma generating source can be of any other type of plasma generating equipment such as that of an ECR reactor, parallel plate reactor, helicon reactor, helical resonator, etc. The plasma generating source can be attached to a modular mounting arrangement such as an annular mounting flange which is removably mounted on the endwall of the chamber.

In order to maintain a vacuum tight seal between the mounting flange and the chamber 2, suitable O-ring seals can be fitted within grooves in the endwall of the chamber 2 and RF shielding members can surround the vacuum seals. If a large vacuum force is provided by the vacuum pump, it is not necessary to utilize fasteners for attaching the mounting flange to the chamber 2. Instead, the mounting flange can simply rest on the endwall of the chamber 2. If desired, the mounting flange or another part of the plasma generating source assembly can be hinged to the chamber 2 such that the plasma generating source can be pivoted to an orientation such as a vertical orientation for servicing the interior 4 of the chamber 2.

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The chamber includes a ceramic liner such as a silicon or silicon carbide liner 20. A plasma screen 22 for confining the plasma in the space surrounding the wafer extends inwardly from the lower end of the liner 20. The liner 20 can be supported by an elastically bendable frame which includes an inner support frame 24 and an outer support frame 26. In order to maintain the liner at a desired temperature during processing of a substrate, a heater 28 is provided on the top of the inner frame support 24. In operation, the heater 28 is effective to heat the liner 20 and removal of heat from the liner 20 can be accomplished by a temperature controlled member 30 which withdraws heat from the liner through the inner and outer frames.

As shown in FIG. 5, the chamber can have a modular design which allows various plasma generating sources to be mounted thereon. Further, the substrate support 8 can be supported at one end of a support arm mounted in a cantilever fashion such that the entire substrate support/support arm assembly can be removed from the chamber by passing the assembly through an opening 32 in the sidewall of the chamber.

According to a first embodiment of the invention, the plasma chamber liner 20 comprises interlocking ceramic liner elements such as flat tiles 34, as shown in FIGS. 6 and 7. To provide an electrical ground path for the plasma, the liner elements are preferably of an electrically conductive material such as silicon or silicon carbide. Such a material provides an added benefit in that it does not contain aluminum and thus reduces Al contamination of processed substrates. According to a preferred embodiment, SiC tiles are bonded to an aluminum backing

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plate 36. A preferred bonding material is an electrically conductive elastomer 38 which can absorb lateral stresses caused by different thermal expansion coefficients of the SiC and Al. Each tile and backing plate assembly can be attached to the Al chamber wall by an elastically bendable frame 40 which includes an inner frame 42 and an outer frame 44. Temperature control of the liner is achieved by a heater 48 supplied power by electrical leads 49 and a temperature controlled member 50.

The elastomeric joint can comprise any suitable elastomeric material such as a polymer material compatible with a vacuum environment and resistant to thermal degradation at high temperatures such as above 200°C. The elastomer material can optionally include a filler of electrically and/or thermally conductive particles or other shaped filler such as wire mesh, woven or non-woven conductive fabric, etc. Polymeric materials which can be used in plasma environments above 160°C include polyimide, polyketone, polyetherketone, polyether sulfone, polyethylene terephthalate, fluoroethylene propylene copolymers, cellulose, triacetates, silicone, and rubber. Examples of high purity elastomeric materials include one-component room temperature curing adhesives available from General Electric as RTV 133 and RTV 167, a one-component flowable heat-curable (e.g. over 100°C) adhesive available from General Electric as TSE 3221, and a two-part addition cure elastomer available from Dow Corning as "SILASTIC." An especially preferred elastomer is a polydimethylsiloxane containing elastomer such as a catalyst cured, e.g. Pt-cured, elastomer available from Rhodia as V217, an elastomer stable at temperatures of 250°C and higher.

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In the case where the elastomer is an electrically conductive elastomer, the electrically conductive filler material can comprise particles of an electrically conductive metal or metal alloy. A preferred metal for use in the impurity sensitive environment of a plasma reaction chamber is an aluminum alloy such as a 5-20 weight % silicon containing aluminum base alloy. For example, the aluminum alloy can include about 15 wt % silicon.

A plasma screen 52 extends inwardly from a lower edge of the tiles 34. The plasma screen 52 is preferably of an electrically conductive ceramic material such as silicon or silicon carbide and includes openings 54 which are small enough to confine the plasma but allow process gas and processing byproducts to be removed by the vacuum pump.

The heater 48 can comprises an electrical resistance heating element embedded in an aluminum casting. Thus, by passing electrical current through the heating element, heat will be supplied to the aluminum casting which in turn conducts heat into the inner frame 42, the aluminum backing plates 36, the heat conductive elastomer 38 and into the tiles 34. During heating and cooling of the aluminum body of the heater, the heater will expand to a greater extent than the ceramic liner formed by the tiles 34. The elastomer bond accommodates such expansion and contraction. In addition, the inner and outer frames can be configured to provide a desired amount of thermal conductance to center the operating temperature in the desired range.

FIG. 8 shows a portion of the chamber wall wherein a substrate such as a wafer can be introduced and removed from the chamber through a transport slot 55.

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In the arrangement shown in FIG. 8, some of the tiles 34 are shorter in the axial direction in the vicinity of the slot 55. The slot 55 can be formed from an integral piece of ceramic material. FIG. 8 shows details of how the inner support frame can be fitted around the slot 55. The outer support frame (not shown) can be configured in a similar manner.

In order to prevent a line of sight between the wafer and the Al chamber wall 46, each tile 34 can have edges 56 which interlock with mating edges of adjacent tiles, as shown in FIG. 9.

FIG. 10 shows a further embodiment of the invention wherein the ceramic liner comprises a continuous free standing cylindrical liner 70 which is bonded to backing plates 36 by the electrically and thermally conductive elastomer. FIG. 10 also shows details of the inner and outer frames 42, 44. As shown, the outer frame 44 includes segments 45 separated by a series of axially extending slots 45a. Likewise, the inner frame 42 includes segments 43 separated by a series of axially extending slots 43a. The segments 43, 45 have the same width in the circumferential direction as the individual backing plates 36. The segmented resilient frame shown in FIG. 10 can be used for the inner and outer frame arrangements of the embodiments of the invention described above.

According to a further embodiment of the invention, Al flanges 72 are bonded with the thermally and electrically conductive elastomer to the exterior of a continuous cylindrical ceramic liner 70, as shown in FIG. 11. In the case of a thin liner, the flanges are preferably of a length which substantially covers the outside of the liner. However, in the case of a thick liner, the flanges can be shorter, e.g., the

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flanges for thick liners can be relatively short in length like the flanges 73 located beneath the wafer transport slot 71 in FIG. 8. The flanges are preferably of a metal such as aluminum and are bent outwardly at the bottom thereof for attachment to an elastically bendable support frame. The support frame preferably provides temperature control of the liner by conducting heat from a heater through the support frame and flanges into the liner.

To remove heat from the liner, a temperature controlled member in thermal contact with the support frame can be used as a heat sink to draw heat from the liner through a heat flow path passing through the flanges, the support frame and into the temperature controlled member. The flanges can be discrete pieces which are not connected together or they can be portions of a segmented ring. Accordingly, the flanges can be designed to accommodate differential thermal expansion between the resilient support and the ceramic cylinder. The heat generated by absorbed ion energy built up on the cylinder can flow to the chamber through the flanges and the support connecting the flange to the SiC cylinder. In the case where the support includes the segmented inner and outer metal frames, the segmented outer support can move radially with respect to a portion thereof attached to the chamber. With the resilient support arrangement according to the invention, such radial movement, however, produces a low enough radial force which does not overstress the elastomer bond between the flanges and the ceramic liner.

In the foregoing embodiments, the plasma in the chamber can be confined by the Si or SiC surfaces of the gas distribution plate, the liner, the plasma screen and

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the substrate support which extends upwardly through the inner periphery of the plasma screen. Because the Si and SiC surfaces are located between the plasma and Al surfaces of the chamber, sputtering of the Al surfaces by the plasma is minimized and contaminating processed wafers with Al is reduced compared to chambers having Al surfaces with line-of-sight to the processed wafer.

In the embodiment wherein the liner comprises Si or SiC tiles bonded to an aluminum backing plate by an electrically and/or thermally conductive elastomer bonding material, the tiles can be sized and/or configured to fit together in a manner which covers the circumference of an inner wall of the plasma chamber. A suitable access opening allows passage of individual wafers into and out of the chamber and additional openings can be provided to allow various measurements to be made by conventional accessories such as process monitoring equipment. In the tile embodiment, the inner wall of the chamber can be cylindrical or polygonal. In the case of cylindrical inner wall, a frame can be interposed between the backing plates and the inner wall or the backing plates can have a matching curved surface which is bonded to the inner wall with the elastomer bonding material. The tiles can have a flat rectangular surface facing the interior of the chamber.

Alternatively, the exposed surface of the tiles can be curved such that the tiles form a cylindrical inner wall of the chamber.

In the embodiment wherein the tile and backing plate assemblies are bolted to an Al inner support frame which extends around the inner wall of the chamber, the thermal stresses generated during start-up, operation and shut-down of the plasma chamber can be accommodated. In contrast, if a continuous ring of SiC was

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bonded to the support frame, the part and bond stresses would be excessive due to the differing coefficients of thermal expansion. Accordingly, the number of SiC tiles can be chosen to achieve a desired limit on part and/or bond stresses generated due to thermal forces encountered in the plasma chamber.

In the embodiment wherein a lower flange of the inner support frame is bolted to the lower edge of an Al outer support frame and a flange at the upper edge of the outer support frame is bolted to a top plate located on top of the chamber, the outer support is segmented into vertically extending plates separated by slots which extend from the lower end of the outer support frame to the top flange. In order to provide temperature control of the SiC tiled surface, a heater located above the top flange of the inner support frame can be bolted to the inner frame. With such an arrangement, the heater can generate heat which is thermally conducted from the inner support frame to the backing plate and SiC tile. The heater can comprise a single resistance heater which extends entirely around the inner wall of the chamber. Alternatively, the heater can comprise any suitable heater arrangement which achieves the desired temperature control of the liner, e.g., maintaining the inner surface of the liner at a desired temperature such as in the range of 80 to 150°C during plasma etching of dielectric materials such as silicon oxide.

The chamber can include a plasma screen surrounding the substrate support. The annular screen can be attached to a carrier ring by any suitable technique. For instance, the screen can be adhesively bonded to the carrier ring by the elastomer bonding material discussed earlier. In addition, the carrier ring can be bolted to a lower flange on the inner frame such that the screen is clamped between the carrier

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ring and the flange. The screen can be of any suitable material which will withstand a plasma environment for semiconductor production. Silicon carbide is a preferred material for the screen. The screen can comprise a single unitary ring or a plurality of spaced apart ring segments. For instance, the screen can include circumferentially spaced apart segments.

In the embodiments wherein a wafer is transferred into and out of the chamber through a transport slot, the inner and outer frames include cut-outs therein and the tiles surrounding the slot are arranged such that smaller tiles are below the slot and larger tiles are above the slot. The interior of the slot can be formed by a wafer passage insert. A preferred material for the insert is silicon carbide. The insert can comprise a single piece of material or an assembly of several pieces of material. The medium height tiles and short tiles are preferably adhesively bonded with the elastomer to similarly sized backing plates which in turn are bolted to the inner frame.

According to the embodiment of the invention wherein line-of-sight surfaces of aluminum components are avoided by covering the surfaces with the SiC tiles, the edges of the tiles are preferably designed such that they overlap each other. For instance, the tiles can have mating edges wherein a projection on one tile is received in a recess in an adjacent tile. This effect can be obtained by any edge design wherein a rectilinear path is not provided between the opposed surfaces of the tile. Thus, a mating curved or multi-sided edge surface such as a V-shaped, U-shaped, W-shaped, groove-shaped, notch-shaped, offset-shaped, etc. type edge can provide the desired mating tile edge.

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The interlocking tile joints eliminate line-of-sight to aluminum components and accommodate differential thermal expansion/contraction of liner components during startup, operation and/or shutdown of the plasma reactor. For instance, heat from the heater and/or plasma ion thermal energy deposited on the tiles is thermally conducted by inner support, through the elastomer bond, up the outer support and into the chamber top plate. Due to water cooling of the top plate via cooling channels, the heat transferred through outer support is removed from the chamber.

During processing of semiconductor substrates, the tiles can be preheated by the heater before plasma is generated in the chamber. For instance, the tiles can be heated to a desired temperature by the heater and a thermal control system can be used to adjust the heater power to maintain the tiles at the desired temperature. After plasma is generated in the chamber, the control system can automatically reduce the heater power to maintain the desired temperature. Further, the thermal impedances of the inner and/or outer supports can be adjusted to achieve the desired range of tile operating temperatures and limit the heater maximum temperature.

FIG. 12 shows measured temperatures at the inner support heater flange, the inner support lower flange, and the tile backing plate during plasma etching of a batch of semiconductor wafers. The 2°C temperature oscillations resulted from variations in plasma ion energy during an etch cycle. The temperature set point for the lower flange was 100°C.

In the embodiment wherein the ceramic liner is a continuous single piece of SiC, the SiC cylinder is supported by a segmented aluminum flange at its lower end. The segmented aluminum flange is attached to an elastically bendable frame

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supported by the chamber. As in the other embodiments, a heater supplies heat which travels through the inner support, through the lower flanges of the backing plates, through the elastomer bond and into the SiC liner. The lower flange of the inner frame is attached (e.g., bolted) to the lower flange of the outer support frame such that the entire liner arrangement including the SiC liner, backing plates, and inner and outer support frames are supported by the upper flange of the outer support frame which attaches to a water cooled top plate of the reactor. The provision of the individual backing plates and slotted inner and outer support frames allow the SiC liner to be supported in a manner which accommodates differential thermal stresses generated during start-up, operation and/or shut-down of the reactor. For instance, the heater can expand radially outward more than the SiC cylinder due to the higher temperature of the heater and greater coefficient of thermal expansion of Al compared to SiC. The relative radial expansion is accommodated by bending of the thin, vertical flexures of inner support. Likewise, differential radial growth between the bottom and top of the outer support due to a vertical temperature gradient is accommodated by the thin vertical flexures of the outer support.

The foregoing has described the principles, preferred embodiments and modes of operation of the present invention. However, the invention should not be construed as being limited to the particular embodiments discussed. Thus, the above-described embodiments should be regarded as illustrative rather than restrictive, and it should be appreciated that variations may be made in those

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embodiments by workers skilled in the art without departing from the scope of the present invention as defined by the following claims.

WHAT IS CLAIMED IS:

1. An electrode assembly useful for a plasma reaction chamber used in semiconductor substrate processing, comprising:

a support member having a bonding surface;

an RF driven electrode having an RF powered surface on one side thereof and a bonding surface at an outer edge on an opposite side thereof engaging the bonding surface of the support member; and

an elastomeric joint between the outer edge of the electrode and the support member, the elastomeric joint resiliently attaching the electrode to the support member so as to allow movement between the electrode and the support member during temperature cycling thereof.

2. The electrode assembly of Claim 1, wherein the support member is removably attached to a temperature-controlled member in an interior of a plasma reaction chamber, the support member comprising a support ring clamped to the temperature-controlled member, the electrode comprising a showerhead electrode and the temperature-controlled member including a gas passage supplying a process gas to the showerhead electrode.

3. The electrode assembly of Claim 2, wherein the temperature-controlled member includes a cavity and at least one baffle plate located in the cavity, the gas

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passage supplying process gas so as to pass through the baffle prior to passing through the showerhead electrode.

4. The electrode assembly of Claim 1, wherein the elastomeric joint comprises an electrically conductive elastomeric material in an interface between the electrode and the support member, the elastomeric material including an electrically conductive filler which provides an electrical current path between the electrode and the support member.

5. The electrode assembly of Claim 4, wherein a recess is provided in the interface and the filler comprises electrically and/or thermally conductive particles, the particles having an average size at least 5 times smaller than a depth of the recess in the interface.

6. The electrode assembly of Claim 5, wherein the recess has a uniform depth in the support member, the recess being located between walls of the support member, the walls having a thickness greater than the depth of the recess but less than 25 times the depth of the recess.

7. The electrode assembly of Claim 4, wherein the recess extends continuously around the support member, the electrode being bonded to the support member only by the elastomeric joint.

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8. The electrode assembly of Claim 1, wherein the elastomeric joint comprises a catalyst-cured elastomer resin.

9. The electrode assembly of Claim 1, wherein the electrode comprises a silicon electrode and the support member comprises a graphite support ring.

10. A method of manufacturing an electrode assembly for use in a plasma reaction chamber, comprising:

applying an elastomeric bonding material to one or more mating surfaces of a support member and an RF driven electrode;

forming an assembly of the support member and electrode such that the elastomeric bonding material joins the mating surfaces of the support member and electrode; and

curing the elastomeric bonding material so as to form an elastomeric joint between the electrode and the support member, the elastomeric joint allowing movement of the electrode relative to the support member during temperature cycling thereof.

11. The method of Claim 10, further comprising preparing the elastomeric bonding material by mixing at least two components of an elastomer with an optional electrically conductive filler and densifying the elastomeric bonding material in a vacuum environment at ambient or a temperature above or below ambient.

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12. The method of Claim 10, further comprising applying masking material to surfaces of the electrode and support member so as to leave the mating surfaces exposed and optionally coating exposed portions of the masking material with a primer material which removes excess elastomeric bonding material squeezed out of the elastomeric joint when the masking material is removed from the electrode and support member.

13. The method of Claim 10, wherein the support member comprises a support ring having an annular recess which extends completely around the support ring, the elastomeric bonding material being applied in an amount such that the elastomeric joint fills the recess and is thin enough to conduct heat from the electrode to the support ring.

14. The method of Claim 10, wherein the elastomeric bonding material includes an electrically conductive filler, the elastomeric bonding material being applied to the mating surfaces so as to provide substantially direct electrical contact between the electrode and the support member.

15. The method of Claim 10, wherein the electrode consists essentially of single crystal or polycrystalline silicon and the support member consists essentially of graphite, the silicon electrode being bonded to the graphite support member solely by the elastomeric joint.

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16. The method of Claim 10, wherein the electrode comprises a silicon disk of uniform or nonuniform thickness and the support member comprises a graphite support ring, the method including aligning the electrode and support ring in a fixture, applying pressure sufficient to force excess bonding material outwardly of an interface between the electrode and the support ring, heating the assembly in an oven at a temperature high enough to accelerate curing of the elastomeric bonding material but low enough to minimize thermal expansion of the electrode or support ring.

17. The method of Claim 10, wherein the elastomeric bonding material is filled into a recess sized to provide a cured elastomeric joint which allows sufficient movement between the electrode and support member to prevent tearing of the joint as a result of differential thermal expansion or contraction of the electrode and support member during use of the electrode assembly in a plasma reactor.

18. The method of Claim 10, wherein the elastomeric bonding material has a viscosity sufficient to achieve self-leveling and spreading of the bonding material on the mating surfaces, the method further comprising degassing the bonding material by placing the assembly in a vacuum environment.

19. The method of Claim 10, further comprising applying a primer material to the mating surfaces or plasma treating the mating surfaces.

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20. A method of processing a semiconductor substrate in a plasma reaction chamber wherein an electrode assembly includes an RF driven electrode bonded to a support member by an elastomeric joint, comprising:

supplying a semiconductor substrate to the plasma reaction chamber;

supplying process gas to an interior of the plasma reaction chamber;

supplying RF power to the electrode such that the RF power passes from the support member, through the elastomeric joint and to the electrode, the RF power causing the process gas to form a plasma in contact with an exposed surface of the semiconductor substrate, the elastomeric joint allowing the electrode to move relative to the support member during temperature cycling of the electrode assembly.

21. The method of Claim 20, wherein the semiconductor substrate comprises a silicon wafer and the method includes etching a dielectric or conductive layer of material on the wafer.

22. The method of Claim 20, wherein the method includes depositing a layer of material on the semiconductor substrate.

23. The method of Claim 20, wherein the electrode comprises a silicon showerhead electrode and the support member comprises a graphite ring, the graphite ring being clamped to a temperature-controlled member through which the process gas is supplied to the showerhead electrode.

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24. An elastomeric joint assembly in a plasma reaction chamber used in semiconductor substrate processing, comprising:

a first part having a bonding surface;

a second part having a bonding surface engaging the bonding surface of the first part; and

an elastomeric joint between the first part and the second part, the elastomeric joint resiliently attaching the first part to the second part so as to allow movement between the first part and the second part during temperature cycling thereof.

25. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint comprises a polymeric material compatible with a vacuum environment and resistant to thermal gradation at temperatures of up to and including 200°C, the polymeric material comprising polyimide, polyketone, polyetherketone, polyether sulfone, polyethylene terephthalate, fluoroethylene propylene copolymers, cellulose, triacetates or silicone.

26. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint includes a filler of electrically and/or thermally conductive particles.

27. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint includes a filler of wire mesh, woven or non-woven fabric.

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28. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint includes a filler of metal particles .

29. The elastomeric joint assembly of Claim 28, wherein the metal particles comprise aluminum or an aluminum alloy.

30. The elastomeric joint assembly of Claim 29, wherein the metal filler comprises an aluminum silicon alloy.

31. The elastomeric joint assembly of Claim 30, wherein the aluminum silicon alloy includes 5 to 20 weight % silicon.

32. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint is located in a recess in the first part.

33. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint includes a filler having a particle size of 0.7 to 2 μm .

34. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint includes an electrically and/or thermally conductive filler in an amount of 45 to 55 volume %.

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35. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint is provided between mating surfaces of the first and second parts.

36. The elastomeric joint assembly of Claim 35, wherein the mating surfaces are contoured to provide an interlocking and/or self-aligning arrangement.

37. The elastomeric joint assembly of Claim 24, wherein the first part is removably attached to a temperature-controlled member in an interior of a plasma reaction chamber.

38. The elastomeric joint assembly of Claim 24, wherein second part comprises a showerhead electrode.

39. The elastomeric joint assembly of Claim 24, wherein the elastomeric joint comprises a thermally conductive elastomeric material in an interface between the first part and the second part, the elastomeric material including an electrically conductive filler which provides a thermally conductive path between the first part and the second part.

40. The elastomeric joint assembly of Claim 39, wherein a recess is provided in the interface and the filler comprises electrically and/or thermally conductive particles, the particles having an average size at least 5 times smaller than a depth of the recess in the interface.

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41. The elastomeric joint assembly of Claim 24, wherein the first part comprises an electrode and the second part comprises a support member.

42. A plasma processing system useful for processing semiconductor substrates comprising:

a plasma processing chamber having an interior space bounded by a chamber sidewall;

a substrate support on which a substrate is processed within the interior space, the chamber sidewall being spaced outwardly of a periphery of the substrate support;

a gas supply through which process gas can be supplied to the interior space during processing of the substrate;

an energy source which can energize the process gas in the interior space into a plasma state during processing of the substrate;

a liner supported between the chamber sidewall and the periphery of the substrate support, the liner comprising a ceramic member supported by a resilient support member.

43. The plasma processing system of Claim 42, wherein the resilient support member comprises an elastomeric joint or a bendable metal frame.

44. The plasma processing system of Claim 42, wherein the ceramic member comprises a one-piece ceramic liner or an assembly of ceramic tiles.

45. The plasma processing system of Claim 42, wherein the ceramic member comprises an assembly of ceramic tiles and metal backing members, the resilient support comprises an elastomeric joint, and the elastomeric joint attaches each of the ceramic tiles to a respective one of the metal backing members.

46. The plasma processing system of Claim 45, wherein the metal backing members are supported on a bendable metal frame and the bendable metal frame is supported by a thermally controlled member such that heat can be withdrawn from the ceramic tiles via a thermal path which extends through the elastomeric joint, the metal backing members and the bendable metal frame to the thermally controlled member.

47. The plasma processing system of Claim 42, wherein the ceramic member comprises an assembly of ceramic tiles and the resilient support comprises an elastomeric joint between each of the ceramic tiles and the chamber sidewall.

48. The plasma processing system of Claim 42, wherein the resilient support comprises a bendable metal frame, the bendable metal frame being supported by a thermally controlled member such that heat can be removed from the ceramic member through a thermal path extending through the bendable metal frame to the thermally controlled member.

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49. The plasma processing system of Claim 48, further comprising a heater supported by the bendable metal frame such that the heater can heat the ceramic member.

50. The plasma processing system of Claim 42, wherein the resilient support member comprises a bendable metal frame which includes an inner frame member and an outer frame member, the resilient support member further comprising an elastomeric joint between the ceramic member and the inner frame member, the inner frame member being supported by the outer frame member, and the outer frame member being supported by the chamber.

51. The plasma processing system of Claim 42, wherein the ceramic member comprises a plurality of interlocking ceramic tiles.

52. The plasma processing system of Claim 42, wherein the ceramic member comprises a one-piece SiC liner or a plurality of SiC tiles.

53. The plasma processing system of Claim 42, wherein resilient support member comprises inner and outer metal frame members configured to allow differential thermal stresses on the ceramic member and the frame members to be accommodated during operation of the plasma processing system.

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54. The plasma processing system of Claim 53, wherein an upper portion of the outer frame member is supported by a thermally controlled part of the chamber, a lower portion of the outer frame member is attached to a lower portion of the inner frame member, and the ceramic member is supported by the inner frame member.

55. The plasma processing system of Claim 42, wherein the resilient support member comprises a bendable metal frame, the bendable metal frame including a continuous upper portion and a segmented lower portion

56. The plasma processing system of Claim 55, wherein the bendable metal frame is cylindrical and the segmented lower portion comprises axially extending segments separated from each other by axially extending slots.

57. The plasma processing system of Claim 53, wherein the inner and outer metal frame members are cylindrical and include continuous upper portions and segmented lower portions, the segmented lower portions comprising axially extending segments separated from each other by axially extending slots.

58. The plasma processing system of Claim 42, wherein the liner further includes a ceramic plasma screen extending inwardly from a lower portion of the ceramic member, the ceramic plasma screen including passages through which

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process gas and reaction byproducts are removed from the interior of the chamber during processing of a substrate.

59. The plasma processing system of Claim 58, wherein the ceramic plasma screen comprises a plurality of segments supported in an annular space between the chamber sidewall and the substrate support, the passages comprising slots extending radially inwardly from the chamber sidewall.

60. The plasma processing system of Claim 58, wherein the ceramic plasma screen is attached to the resilient support member by an electrically conductive elastomeric joint, the resilient support member comprising a bendable metal frame and the plasma screen being electrically grounded to the bendable metal frame by the elastomeric joint.