REPLACEABLE UPPER CHAMBER PARTS OF PLASMA PROCESSING APPARATUS

[0001] This application claims priority under 35 U.S.C. §119 to U.S. provisional application No. 61/241,321 entitled REPLACEABLE UPPER CHAMBER PARTS OF PLASMA PROCESSING APPARATUS, filed September 10, 2009, the entire content of which is hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention relates in general to semiconductor substrate manufacturing technologies and in particular to a replacement parts of an upper chamber section of a plasma chamber.

BACKGROUND OF THE INVENTION

[0003] In the processing of a substrate, e.g., a semiconductor substrate or a glass panel such as one used in flat panel display manufacturing, plasma is often employed. As part of the processing of a substrate for example, the substrate is divided into a plurality of dies, or rectangular areas, each of which will become an integrated circuit. The substrate is then processed in a series of steps in which materials are selectively removed (etching) and deposited (deposition) in order to form electrical components thereon.

[0004] In an exemplary plasma process, a substrate is coated with a thin film of hardened emulsion (i.e., such as a photoresist mask) prior to etching. Areas of the hardened emulsion are then selectively removed, causing components of the underlying layer to become exposed. The substrate is then placed in a plasma processing chamber on a substrate support structure comprising a mono-polar or bi-polar electrode, called a chuck or pedestal. Appropriate etchant source are then flowed into the chamber and struck to form a plasma to etch exposed areas of the substrate.

[0005] Referring now to FIG. 1, a simplified diagram of inductively coupled plasma processing system components is shown. Generally, the plasma chamber

(chamber) 202 is comprised of a bottom chamber section 250 forming a sidewall of the chamber, an upper chamber section 244 also forming a sidewall of the chamber, and a cover 252. An appropriate set of gases is flowed into chamber 202 from gas distribution system 222. These plasma processing gases may be subsequently ionized to form a plasma 220, in order to process (e.g., etch or deposition) exposed areas of substrate 224, such as a semiconductor substrate or a glass pane, positioned with edge ring 215 on an electrostatic chuck (chuck) 216. Gas distribution system 222 is commonly comprised of compressed gas cylinders (not shown) containing plasma processing gases (e.g., C_4F_8, C_4F_6, CHF_3, CH_2F_3, CF_4, HBr, CH_3F, C_2F_4, N_2, O_2, Ar, Xe, He, H_2, NH_3, SF_6, BCl_3, Cl_2, etc.).

[0006] Induction coil 231 is separated from the plasma by a dielectric window 204 forming the upper wall of the chamber, and generally induces a time-varying electric current in the plasma processing gases to create plasma 220. The window both protects induction coil from plasma 220, and allows the generated RF field 208 to generate an inductive current 211 within the plasma processing chamber. Further coupled to induction coil 231 is matching network 232 that may be further coupled to RF generator 234. Matching network 232 attempts to match the impedance of RF generator 234, which typically operates at about 13.56 MHz and about 50 ohms, to that of the plasma 220. Additionally, a second RF energy source 238 may also be coupled through matching network 236 to the substrate 224 in order to create a bias with the plasma, and direct the plasma away from structures within the plasma processing system and toward the substrate. Gases and byproducts are removed from the chamber by a pump 220.

[0007] Generally, some type of cooling system 240 is coupled to chuck 216 in order to achieve thermal equilibrium once the plasma is ignited. The cooling system itself is usually comprised of a chiller that pumps a coolant through cavities within the chuck, and helium gas pumped between the chuck and the substrate. In addition to removing the generated heat, the helium gas also allows the cooling system to rapidly control heat dissipation. That is, increasing helium pressure increases the heat transfer rate. Most plasma processing systems are also controlled by sophisticated computers comprising operating software programs. In a typical operating environment, manufacturing process parameters (e.g., voltage, gas flow

mix, gas flow rate, pressure, etc.) are generally configured for a particular plasma processing system and a specific recipe.

[0008] In addition, a heating and cooling apparatus 246 may operate to control the temperature of the upper chamber section 244 of the plasma processing apparatus 202 such that the inner surface of the upper chamber section 244, which is exposed to the plasma during operation, is maintained at a controlled temperature. The heating and cooling apparatus 246 is formed by several different layers of material to provide both heating and cooling operations.

[0009] The upper chamber section itself is commonly constructed from plasma resistant materials that either will ground or are transparent to the generated RF field within the plasma processing system (e.g., coated or uncoated aluminum, ceramic, etc.).

[0010] For example, the upper chamber section can be a machined piece of aluminum which can be removed for cleaning or replacement thereof. The inner surface of the upper chamber section is preferably coated with a plasma resistant material such as a thermally sprayed yttria coating. Cleaning is problematic in that the ceramic coatings of this type are easily damaged and due to the sensitive processing of some plasma processes, it is sometimes preferred to replace the upper chamber section rather than remove it for cleaning.

[0011] In addition, correctly reseating the upper chamber section after maintenance is often difficult, since it must properly be aligned with the bottom chamber section such that a set of gaskets properly seal around the upper chamber section. A slight misalignment will preclude a proper mounting arrangement.

[0012] The volume of material in the upper chamber section also tends to add a substantial thermal mass to the plasma processing system. Thermal mass refers to materials have the capacity to store thermal energy for extended periods. In general, plasma processes tend to very sensitive to temperature variation. For example, a temperature variation outside the established process window can directly affect the etch rate or the deposition rate of polymeric films, such as poly-fluorocarbon, on the substrate surface. Temperature repeatability between substrates is often desired, since many plasma processing recipes may also require temperature variation to be on the order of a few tenths of degree C. Because of this, the upper chamber section

is often heated or cooled in order to substantially maintain the plasma process within established parameters.

[0013] As the plasma is ignited, the substrate absorbs thermal energy, which is subsequently measured and then removed through the cooling system. Likewise, the upper chamber section can be thermally controlled. However, plasma processing may require temperature changes during multi-step processing and it may be necessary to heat the upper chamber section to temperatures above 100°C, e.g. 120, 130, 140, 150 or 160°C or any temperature therebetween whereas the prior upper chamber sections were run at much lower temperatures on the order of 60°C. The higher temperatures can cause undesirable increases in temperature of adjacent components such as the bottom chamber section. For example, if it is desired to run the upper chamber section and overlying dielectric window at temperatures on the order of 130 to 150°C and the bottom chamber section at ambient temperatures of about 30°C, heat from the much hotter upper chamber section can flow into the bottom chamber section and raise its temperature sufficiently to affect the plasma processing conditions seen by the semiconductor substrate. Thus, heat flow variations originating from the upper chamber section may cause the substrate temperature to vary outside narrow recipe parameters.

[0014] In view of the foregoing, replaceable upper chamber parts having desired features which cooperate to optimize plasma processing in a plasma processing system would be of interest.

SUMMARY OF THE INVENTION

[0015] In a preferred embodiment, a replaceable top chamber interface of an upper chamber section of a plasma reaction chamber in which semiconductor substrates can be processed, comprises a monolithic metal cylinder having a uniform diameter inner surface, an upper vacuum sealing surface extending horizontally away from the inner surface and a lower vacuum sealing surface extending horizontally away from the inner surface; the upper annular vacuum sealing surface adapted to seal against a dielectric window of the plasma chamber; the lower annular vacuum sealing surface adapted to seal against a bottom section of the plasma chamber; a thermal mass at an upper portion of the cylinder, the thermal mass defined by a

wider portion of the cylinder between the inner surface and an outer surface extending vertically from the upper flange, the thermal mass being effective to provide azimuthal temperature uniformity of the inner surface, and a thermal choke at a lower portion of the cylinder effective to minimize transfer of heat across the lower vacuum sealing surface, the thermal choke defined by a thin metal section having a thickness of less than 0.25 inch and extending at least 25 % of the length of the inner surface.

[0016] In another embodiment, a replaceable window of an upper chamber section of a plasma reaction chamber in which semiconductor substrates can be processed, comprises a ceramic disk having a uniform thickness, at least one blind hole configured to receive a temperature monitoring sensor, a vacuum sealing surface adapted to seal against an upper vacuum sealing surface of a top chamber interface, and a central bore configured to receive a top gas injector which delivers process gas into the center of the chamber.

[0017] In a further embodiment, a gas delivery system configured to supply gas to side injectors mounted in a sidewall of the top chamber interface comprises bifurcated gas lines which receive tuning gas from a common feed and gas tubes arranged to flow the tuning gas equal distances from the common feed to the injectors. The side injectors can include 8 injectors symmetrically arranged around the top chamber interface and the gas lines can include eight gas lines of which two primary gas lines of equal length extend from the common feed, two secondary gas lines of equal length extend from the outlets of the primary gas lines and four tertiary gas lines of equal length extend from outlets of the secondary gas lines. The primary gas lines are longer than the secondary gas lines and the secondary gas lines are longer than the tertiary gas lines. The primary gas lines are connected to midpoints of the secondary gas lines and the secondary gas lines are connected to midpoints of the tertiary gas lines. The gas delivery system is designed to fit within a small volume defined by an annular recess in the outer surface of the top chamber interface.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0018] FIG. 1 shows a simplified diagram of a plasma processing system;

[0019] FIG. 2 shows a perspective view of an exemplary plasma chamber which can include a window, a top chamber interface and a side injector gas supply system as described herein.

[0020] FIGs. 3A-D show details of a top chamber interface as described herein.

[0021] FIGs. 4A-H show details of a ceramic window described herein.

[0022] FIGs. 5A-K show details of a side gas injection delivery system described herein.

[0023] FIGs. 6A-B show details of a gas injector which mounts in an opening in the sidewall of the top chamber interface and is supplied gas by the side gas injection system.

DETAILED DESCRIPTION OF THE INVENTION

[0024] The present invention will now be described in detail with reference to a few preferred embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention. As used herein, the term "about" should be construed to include values up to 10% above or below the values recited.

[0025] Described herein are replaceable parts of an upper chamber section of a plasma chamber such as that illustrated in FIG. 2. The parts include a ceramic window, top chamber interface and side gas injection delivery system.

[0026] The plasma system shown in FIG. 2 includes a chamber 10 which includes a lower chamber 12 and an upper chamber 14. The upper chamber 14 includes a top chamber interface 15 which supports a dielectric window 16. An RF coil 18 overlies the window and supplies RF power for energizing process gas into a plasma state inside the chamber. A top gas injector is mounted in the center of the window for delivering process gas from gas supply line 20.

[0027] FIGs. 3A-D show details of the top chamber interface 15. FIG. 3A is a top view of the top chamber interface 15, FIG. 3B is a side cross sectional view illustrating a thickened wall section 15a, a thin walled section 15b, an upper vacuum sealing surface 15 c, a lower vacuum sealing surface 15d and side injection ports 15e in side wall 15f. FIG. 3C shows details of the upper vacuum sealing surface 15c wherein various dimensions of the surface and of a groove 15g for receipt of an O-ring are set forth. FIG. 3D is a perspective view showing locations of the side gas injectors in an annular recess 15h in the outer wall 15i.

[0028] FIG. 4A shows details of the window 16 which includes a central opening 16a for receipt of a top injector, blind holes 16b in upper surface 16c for receipt of temperature sensors, and a clocking feature 16d in a bottom flange 16e of the outer side surface 16f. FIG. 4B is a side view of the window shown in FIG. 4A. FIG. 4C shows details of a vacuum sealing surface 16g which is outward of a recessed surface which is coated with a ceramic coating such as plasma sprayed yttrium oxide. FIG. 4D is a cross section of the outer periphery of the window wherein a rounded recess 16i extends into the sidewall 16f. FIG. 4 E shows details and dimensions of one of the blind bores 16b. FIG. 4F shows details and dimensions of the clocking feature 16d which is a recess having a radius of 0.625 inch extending into the side of the window at a single location and edges of the recess form an angle of 90° with the center of the radius. FIG. 4G shows details and dimensions of the window and FIG. 4H shows a cross section of the window illustrating the relative depths of the blind bores.

[0029] FIG. 5A shows a top view of the chamber wherein the cylindrical top chamber interface 15 is located within a square housing of the upper chamber 14. FIG. 5B is an enlargement of the upper left corner in FIG. 5A illustrating a bracket arrangement for supporting the top chamber interface. FIG. 5C illustrates a side injection gas supply system 50 which includes a common gas supply feed 50a, two equal length primary gas lines 50b, two equal length secondary gas lines 50c, four equal length tertiary gas lines 50d and eight connections 50e which deliver tuning gas to eight side injector locations. FIG. 5D shows how the gas injection system 50 (wherein tuning gas travels the same distance from the common feed 50a to each of the side injectors) fits within a small volume defined by the annular recess in the

outer surface of the top chamber interface 15. FIG. 5E shows details of the common gas feed 50a and the two primary gas lines 50b which terminate in a connection 50f. FIG. 5F shows details of one of the secondary gas lines 50c bifurcated by gas connection 50g (which connects to gas connection 50f) and two tertiary gas lines 50d bifurcated by connections 50h which connect to ends of the secondary gas lines 50c. FIG. 5G shows details of a side gas injector 50i mounted in the sidewall of the top chamber interface 15. FIG. 5H shows details of how the primary gas line 50b fits within the annular recess in the sidewall of the top chamber interface 15. FIG. 5I shows details of how the gas injection system delivers gas to one of the side injectors 50i. FIG. 5J shows a side gas injector 50i and FIG. 5K shows a washer 50j which fits between a surface of a side gas injector 50i and an opposed surface in a side injection port 15e of the top chamber interface 15.

[0030] In a preferred embodiment, the top chamber interface is a hard anodized aluminum cylinder that has features for mounting process support hardware (RF input coil, temperature controlled window, alignment features, chamber temperature control hardware, side gas injectors, gas delivery tubing, etc.), sealing vacuum, and conducting electrical current out of the part. The vacuum seals are preferably one or more O-rings at the top and bottom of the cylinder. Electrical conduction is preferably established through the use of a metallic spring RF gasket that fits into a groove on the cylinder and contacts a bare metal strip on an adjacent component. The weight and thermal mass are increased at the upper portion of the cylinder to achieve the desired temperature uniformity. The internal plasma exposed surface can be coated with a ceramic material such as plasma sprayed yttrium oxide.

[0031] FIG. 6A shows an end view of the proximal end of one of the eight side gas injectors 50i and FIG. 6B shows a cross section of the injector 50i taken along lines A-A in FIG. 6A. The injector 50i includes an injector body 60 which has a central bore 61 of uniform diameter of 0.038 to 0.042 inch, preferably 0.040 inch extending axially through proximal and distal end surfaces of the injector body 60. The injector body 60 has a total length of 0.52 to 0.53, preferably 0.526 inch, an outer diameter of 0.2 to 0.3, preferably 0.25 inch at an upstream section 62 which extends 0.275 to 0.285, preferably 0.278 inch and an outer diameter of 0.12 to 0.13, preferably 0.125 inch at the downstream section 63 having a length of 0.245 to

0.250, preferably 0.248 inch. The central bore has an aspect ratio of at least 10, preferably 13 to 14. This aspect ratio of the bore can control back diffusion into the injector to prevent corrosion of the stainless steel gas feed lines. The distal end 64 of the downstream end 63 includes a 45° (±10°) chamfer forming a 0.005 to 0.015, preferably 0.01 inch wide annular surface 65. The corner 66 between the outer surface of downstream section 63 and surface 67 which is perpendicular to and extends between the outer surfaces of the upstream and downstream sections is rounded with a radius of 0.005 to 0.015, preferably 0.01 inch. The surface 67 bears against washer 50j as shown in FIG. 5K. The proximal end surface 68 of the upstream section 62 bears against another washer which surrounds an outlet of the connection 50e as shown in FIG. 5I. As can be seen in FIG. 5I, the distal end of the injector 50i projects beyond the side wall. Preferably the distal end of the injector 50i extends 0.05 to 0.2, more preferably about 0.1 inch into the chamber.

[0032] In accordance with a preferred embodiment, the window is a ceramic disk with a bore in the middle that interfaces with a ceramic gas injector. It also has a raised landing pad of about 0.008 inch which extends about 0.5 inch from the outer periphery on the bottom outer diameter (OD) that interfaces with the top chamber interface. There is an O-ring seal at the interface between the window and the top chamber interface. The ceramic disk is about 1 inch thick and is made from a low loss tangent high purity ceramic material such as alumina and is coated on the bottom recessed surface with yttrium oxide for plasma resistance. The disk has two blind bores on the top surface that accept a thermal couple (TC) and a Resistance Temperature Detector (RTD). The location and depth of the TC and RTD are selected to achieve desired process temperature monitoring and avoid damage to the window. The bottom of the TC and RTD holes have a spherical radius to reduce the stress concentration of the hole.

[0033] The contact area between the top chamber interface and the window determines the amount of heat transferred between these two components. During plasma processing, the middle of the window is hot, and it is desirable for the contact area to conduct heat into the edge of the window to help make the temperature of the OD close to that of the middle. At idle (when plasma is not generated in the chamber), the middle of the window is cold, and it is desirable for

the contact area to not conduct any heat into the window and to match the temperature of the middle of the window.

[0034] The depth of the TC and RTD is established by determining where the neutral axis (zero stress line, it is the line that separates the tensile and compressive stresses) of the window is, and keeping the bottom of the hole above that axis. The analysis can also determine what the temperature difference is at the measured point, and the point of interest. This difference can be accounted for in software used to conduct the analysis.

[0035] The location of the TC and RTD is also analyzed to determine what offset needs to be accounted for in the software. The stress in the window can be correlated to the temperature difference between the middle and OD of the window. This analysis can correlate the temperature of the middle of the window and the temperature of the measured point since the temperature of the middle of the window cannot be measured due to the presence of the top gas injector.

[0036] If the bottom of the holes do not have the spherical radius, the window would have a high stress concentration where the holes are located. Because the inside of the window is subject to the vacuum pressure in the chamber, the window could fracture when there is a thermal gradient from the center to the edge of the window if the bottoms of the holes are not rounded. Adding a spherical radius at the bottom of the holes eliminates sharp edges and therefore reduces the stress and likelihood of fracture.

[0037] The ceramic window can be replaced, serviced, maintained and is easily manufacturable. The window is preferably about 1 inch thick and about 22 inches in diameter. The desired dimensions of the bores for the TC and RTD are 0.494 ± 0.009 inch from the yttrium coated surface and the bores are 180° apart on a radius of about 5.6 inches from the center of the window. The bores have a total depth of about 0.5 inch and the entrances of the bores 16b are tapered at 45° with a diameter of 0.390 inch at the bore entrance. The bottoms of the bores have a diameter of about 0.130 inch.

[0038] The side injection system can deliver a tuning gas and the system is designed to be a removable, serviceable, maintainable, manufacturable, leak resistant, plasma resistant, symmetrically fed 8 port gas injection system. It can

operate within a temperature range of 20°C – 120°C and uses ¼ inch stainless steel tubing and custom designed, low-profile vacuum sealing interfaces. Nearly every surface in the side gas injection system fits within a space of rectangular cross section 0.750 inch wide by 1.612 inches tall and, simultaneously, nearly every surface does not extend outside a diameter of 22.5 inches.

[0039] The function of the side gas injection system is to provide tuning gas uniformly into the plasma. The flow rate and flow uniformity of the side gas injection system are primarily the functions of the inner bore diameter of the eight side gas injectors which are made of solid yttria, total volume of the gas delivery tubes, and symmetric path to all injector locations from the singular gas feed location. Dimensions of the gas injection system can be: inner bore diameter of each solid yttria injector: 0.040 ±0.002 inch, volume of gas injection system from VCR fitting (the gas fitting at the upstream end of common feed 50a): 2.922 in^3, gas travel path length to each injector from VCR fitting: 37.426 inches.

[0040] The vacuum fitting interfaces are smaller than, for example, a K1S fitting and the yttria side gas injector, which is the only piece of the system directly exposed to plasma, can be minimized in size and replaced when consumed without having to replace the much more expensive stainless steel weldments.

[0041] The top chamber interface is an anodized and ceramic-coated aluminum cylinder with O-ring seals on top and bottom and a top contact surface mating with the ceramic window. The top chamber is actively heated and maintained at a constant temperature for repeatable wafer processing.

[0042] The temperature at the edge of the window is largely controlled by the interface to the top chamber. The chamber interface largely controls how much heat goes into or is removed from the edge of the window. Thus in order to keep the edge cool during idle and hot during wafer processing it is desirable to keep temperature gradients small during idle or processing so that an optimum heat flow across the interface is provided. Too much heat flow during idle will cause the edge to get too hot and fracture the window. Too little heat flow during wafer processing will cause the edge to be too cold, and lead to fracture. The feature of the interface which largely controls the heat flow across the interface is the contact surface area of the chamber to the window in air. The in-air contact region is from the outer

diameter of the O-ring groove to the outer diameter of the chamber where the window contacts the chamber. These dimensions can be optimized by analysis and testing for the heat flow during idle and during wafer processing.

[0043] In addition, the flatness of the interface is critical to the heat transfer and must be maintained. Various desired dimensions include outer O-ring groove diameter Ø1 = 21.290 ± 0.007 inch, chamber contact region outer diameter Ø2 = 22.00 ±0.005 inch, chamber contact region flatness 0.002 inch.

[0044] Having disclosed exemplary embodiments and the best mode, modifications and variations may be made to the disclosed embodiments while remaining within the subject and spirit of the invention as defined by the following claims.

WHAT IS CLAIMED IS:

1. A replaceable upper chamber part of a plasma reaction chamber in which semiconductor substrates can be processed, comprising a window, side gas delivery system and/or top chamber interface, wherein:

the top chamber interface comprises a monolithic metal cylinder having a uniform diameter inner surface, an upper flange extending horizontally away from the inner surface and a lower flange extending horizontally away from the inner surface; an upper annular vacuum sealing surface adapted to seal against a dielectric window of the plasma chamber; a lower annular vacuum sealing surface adapted to seal against a bottom section of the plasma chamber; a thermal mass at an upper portion of the cylinder, the thermal mass defined by a wider portion of the cylinder between the inner surface and an outer surface extending vertically from the upper flange, the thermal mass being effective to provide azimuthal temperature uniformity of the inner surface, and a thermal choke at a lower portion of the cylinder effective to minimize transfer of heat across the lower vacuum sealing surface, the thermal choke defined by a thin metal section having a thickness of less than 0.25 inch and extending at least 25 % of the length of the inner surface;

the window comprises a ceramic disk having a uniform thickness, at least one blind hole configured to receive a temperature monitoring sensor, a vacuum sealing surface adapted to seal against an upper flange of a top chamber interface, and a central bore configured to receive a top gas injector which delivers process gas into the center of the chamber; and/or

the gas delivery system comprises bifurcated gas lines which receive tuning gas from a common feed and gas tubes arranged to flow the tuning gas equal distances from the common feed to injectors mounted in a side wall of the top chamber interface.

2. The replaceable upper chamber part of claim 1, wherein the gas delivery system includes eight injectors symmetrically arranged around the top chamber interface and the gas lines can include eight gas lines of which two primary gas lines of equal length extend from the common feed, two secondary gas lines of equal

length extend from the outlets of the primary gas lines and four tertiary gas lines of equal length extend from outlets of the secondary gas lines.

3. The replaceable upper chamber part of claim 2, wherein the primary gas lines are longer than the secondary gas lines and the secondary gas lines are longer than the tertiary gas lines, the primary gas lines are connected to midpoints of the secondary gas lines and the secondary gas lines are connected to midpoints of the tertiary gas lines.

4. The replaceable upper chamber part of claim 1, wherein the gas delivery system is designed to fit within a small volume defined by an annular recess in the outer surface of the top chamber interface.

5. The replaceable upper chamber part of claim 1, wherein the outer surface of the top chamber interface includes an annular recess and the gas delivery system is fitted completely within a volume defined by the annular recess.

6. The replaceable upper chamber part of claim 1, wherein the window includes two blind bores in the upper surface, the bores configured to mount temperature sensing probes therein.

7. The replaceable upper chamber part of claim 1, wherein the window includes a central opening, the opening configured to provide a locking engagement with a cylindrical gas injector body having a central gas passage which delivers process gas to an open space in the chamber beneath the window.

8. The replaceable upper chamber part of claim 1, wherein the top chamber interface includes a groove in the upper flange configured to receive an O-ring which provides a vacuum seal between the window and the top chamber interface.

9. The replaceable upper chamber part of claim 1, wherein the window includes a thermally sprayed yttria coating on a lower surface thereof.

10. The replaceable upper chamber part of claim 1, wherein the top chamber interface is anodized aluminum.

11. A ceramic side gas injector configured to mount in any one of eight symmetrically arranged gas injector mounting holes in a side wall of a top chamber interface of a plasma reaction chamber in which semiconductor substrates can be processed, the side gas injector consisting of a stepped cylindrical ceramic body having an upstream section of larger diameter than a downstream section, and a uniform diameter central bore extending in an axial direction through axial end surfaces of the injector body.

12. The gas injector of claim 11, wherein the central bore has a diameter of 0.038 to 0.042 inch and length of 0.52 to 0.53 inch.

13. The gas injector of claim 11, wherein the ceramic body consists entirely of yttria.

14. The gas injector of claim 11, wherein the upstream section is sized to fit in a wider portion of the mounting hole and the downstream section is sized to fit in an opening in a plasma exposed surface of the side wall of the top chamber interface such that a distal end of the injector projects 0.05 to 0.2 inch beyond the plasma exposed surface.

15. The gas injector of claim 11, wherein the ceramic body includes a first washer engaging surface on the axial end surface of the upstream section and a second washer engaging surface extending perpendicularly between the upstream section and the downstream section.

16. The gas injector of claim 11, wherein the central bore has an aspect ratio of 13 to 14.

17. The gas injector of claim 11, wherein the injector body has a length of 0.52 to 0.53 inch, a diameter of 0.2 to 0.3 inch at the upstream section and a diameter of 0.12 to 0.13 inch at the downstream section.

18. The gas injector of claim 11, wherein the upstream section has a length of 0.27 to 0.28 inch and the downstream section has a length of 0.24 to 0.25 inch.