PCT

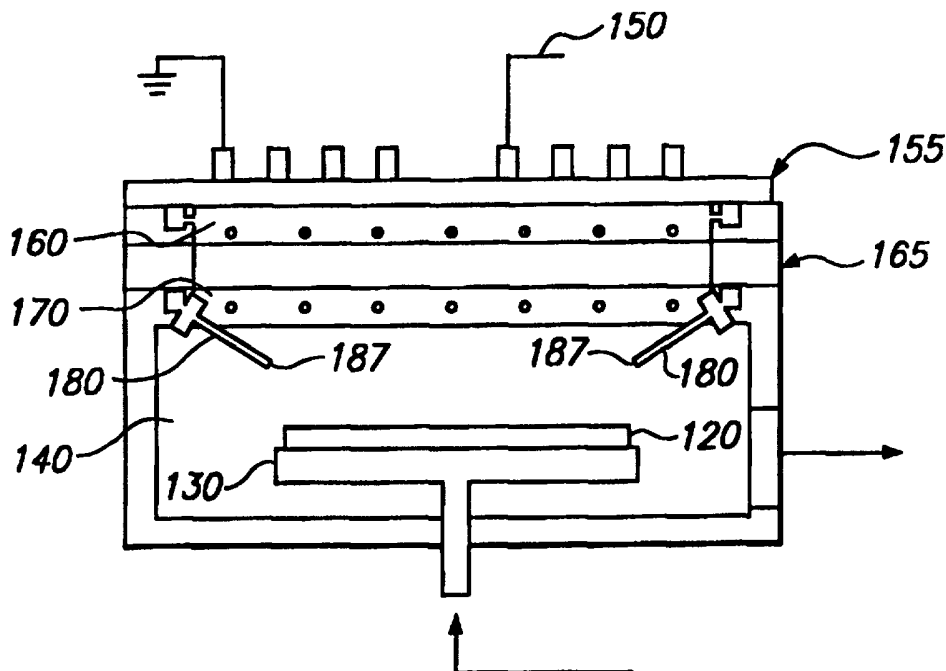## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : C23C 16/50, H01J 37/32, C23C 16/44	A1	(11) International Publication Number: **WO 98/00576** (43) International Publication Date: 8 January 1998 (08.01.98)

(54) Title: APPARATUS AND METHOD FOR HIGH DENSITY PLASMA CHEMICAL VAPOR DEPOSITION

(57) Abstract

A plasma processing system for processes such as chemical vapor deposition includes a plasma processing chamber (140), a substrate holder (130) for supporting a substrate (120) within the processing chamber, a dielectric member (155) having an interior surface facing the substrate holder, the dielectric member forming a wall of the processing chamber, a gas supply for supplying gas to the chamber, directed towards the substrate, and an RF energy source such as a planar coil (150) which inductively couples RF energy through the dielectric member and into the chamber to energize the process gas into a plasma state. The gas supply may comprise a primary gas ring (170) and a secondary gas ring (160) for supplying gases or gas mixtures into the chamber. The gas supply may further include injectors (180) attached to the primary gas ring which inject gas into the chamber, directed towards the substrate. The plasma processing system may also include a cooling mechanism for cooling the primary gas ring during processing.

APPARATUS AND METHOD FOR HIGH DENSITY PLASMA CHEMICAL VAPOR DEPOSITION

Field of the Invention

5   The present invention relates to a system and a method for delivering

reactants to a substrate in a high density plasma chemical vapor deposition

reactor. More particularly, the present invention relates to a system and a

method for focusing the delivery of reactants via a gas injection system towards

a substrate during processing of the substrate in a high density plasma chemical

10   vapor deposition reactor and thermally controlling the gas injection hardware.

Background of the Invention

Vacuum processing chambers are generally used for chemical vapor

depositing (CVD) of materials on substrates by supplying process gas to the

vacuum chamber and applying an RF field to the gas. A number of gas

15   distribution systems for integrated circuit processing are known, but the vast

majority of known systems are designed for plasma etching or for plasma

enhanced CVD (PECVD). Conventional gas distribution systems typically

deliver reactants at relatively low flow rates. Showerhead gas injection and

diffusive transport systems are commonly used to ensure even distribution over

20   the substrate.

These known systems are not optimized for high density plasma CVD

(HDPCVD) processes, such as encapsulation and intermetal dielectric gap

filling. In HDPCVD it is important to focus the delivery of reactants such as

silane related species onto a substrate, because silane and its radicals, e.g., SiH_3,

25   SiH_2, SiH, and so on, have high sticking coefficients. Directing the silane

preferentially onto the substrate is advantageous because it maximizes the

substrate deposition rate and minimizes film deposits on various internal

surfaces of the reactor.

Efficient silane utilization in HDPCVD requires the reactant gas to be

30   directed onto the substrate from close proximity, with a high flow rate, and even

distribution, to achieve high deposition rates with good uniformity and film

quality. A showerhead system positioned close to the substrate is not ideal

because it limits the extent of ion diffusion within the plasma which can be

detrimental to plasma and deposition uniformity. Diffusive systems are not

5   adequate for HDPCVD because they cause deposition of reactants on surfaces

other than the substrate being processed. Deposition on non-substrate surfaces

results in an inefficient use of the reactant gases, which necessitates higher flow

rates to reach the desired deposition rate and substrate throughput. These higher

flow rates are costly because of both the additional gas used and the increased

10   pumping capacity necessary for maintaining low pressure within the processing

chamber. Furthermore, deposition on non-substrate surfaces within the chamber

can lead to particulate problems (flaking) caused by differential expansion

between the films and chamber interior surfaces, and process shifts due to

changing wall conditions. Consequently, the chamber must be cleaned more

15   often to remove these chamber deposits, which further reduces substrate

throughput.

A plasma etching system has been proposed in which gas inlets supply

gas into a plasma processing chamber. As shown in Figure 1, this system

includes a plasma source 110 for generating a plasma in a chamber 140 and a

20   gas ring 167 with attached gas inlets supplying process gas into the processing

chamber 140 for processing a substrate 120 on a substrate support 130. This

type of system may also include an additional gas ring 160. Conventionally, the

deposition rate in such a system is increased by concentrating the process gas

above the substrate 120. This is typically done by changing the distance from

25   the gas ring 167 to the substrate 120. The more the process gas is concentrated

toward the area above the center of the substrate, the larger the peak deposition

rate. Unfortunately, in concentrating the process gas near the center of the

substrate, the deposition rate on the outer portion of the substrate may not

increase as much as the center, which leads to a potential decrease in deposition

30   uniformity.

There is thus a need for a gas distribution system which is optimized for HDPCVD and which provides both an improved deposition rate and an improved deposition uniformity.

Summary of the Invention

5   It is an object of the present invention to provide gas distribution system for HDPCVD which provides uniform, high flow rate delivery of reactant gases focused preferentially onto the substrate surface, to both maximize deposition rate on the substrate and to minimize the chamber cleaning requirements. It is another object of the present invention to thermally control the gas injection

10   hardware to reduce particle counts within the chamber by minimizing flaking from internal chamber surfaces and by minimizing particle formation caused by thermal pyrolysis within the injection hardware. It is yet another object of the present invention to improve the deposition rate and uniformity of deposition compared to conventional gas distribution systems.

15   According to one aspect of the invention, a plasma processing system is provided for processing a substrate. The plasma processing system includes a plasma processing chamber, a substrate holder for supporting a substrate within the processing chamber, a dielectric member having an interior surface facing the substrate holder, the dielectric member forming a wall of the processing

20   chamber, a gas supply for supplying process gas (e.g., one or more reactant gases and/or one or more inert gases) into the chamber and towards the substrate, and an RF energy source which inductively couples RF energy through the dielectric member and into the chamber to energize the process gas into a plasma state. The gas supply may include one or more gas rings with or

25   without injectors injecting at least some of the process gas into the processing chamber so as to intersect an exposed surface of the substrate. A cooling mechanism may also be provided to cool the gas supply during processing to minimize film flaking from the gas ring surfaces and prevent excessive heating which could lead to unwanted thermal decomposition of the process gas.

30   According to another aspect of the present invention, a method is provided for processing a substrate. The method includes placing a substrate on

- 3 -

a substrate holder in a processing chamber, an interior surface of a dielectric member forming a wall of the process chamber and facing the substrate holder, supplying process gas into the processing chamber, and energizing the process gas into a plasma state by inductively coupling RF energy through the dielectric

5   member into the processing chamber. Substrates may be consecutively processed in the processing chamber by contacting the substrates with plasma gas. The process gas may be injected into the processing chamber such that at least some of the process gas is directed towards the substrate. In addition, the gas supply hardware may be cooled during processing to minimize flaking and prevent

10   excessive heating.

Brief Description of the Drawings

Figure 1 illustrates a conventional plasma processing system;

Figures 2a and 2b illustrate a plasma processing system according to a first embodiment of the present invention;

15   Figures 3a and 3b show experimental data illustrating the effects of varying the radial location of injectors and the direction of injection, respectively, in the plasma processing system illustrated in Figures 2a and 2b;

Figure 4 illustrates exemplary flow streamlines of gas into the plasma processing system according to the present invention;

20   Figure 5 illustrates qualitatively exemplary directions of a gas directed onto a substrate according to the present invention;

Figure 6 illustrates a plasma processing system according to a second embodiment of the present invention;

Figure 7 illustrates a plasma processing system according to a third

25   embodiment of the present invention;

Figures 8a-8d illustrate detailed views of exemplary injectors in a plasma processing system according to the present invention;

Figures 9a-9c and 10a-10c illustrate detailed views of exemplary injectors and gas rings according to the present invention; and

30   Figure 11 illustrates a detailed view of an exemplary injector according to the present invention.

Detailed Description of the Preferred Embodiments

Figures 2a and 2b illustrate a plasma processing system according to a first embodiment of the present invention. Referring to Figures 2a and 2b, a plasma processing system for processing a substrate 120 comprises a substrate

5 support 130 and a processing chamber 140 enclosing the substrate support. The substrate 120 may be, for example, a semiconductor wafer having diameters such as 4″, 6″, 8″, 12″, etc., a glass substrate for making a flat panel display, and so on. The substrate support 130 may comprise, for example, a radio frequency (RF) biased electrode. The substrate support 130 may be

10 supported from a lower endwall of the chamber 140 or may be cantilevered, extending from a sidewall of the chamber 140. The substrate 120 may be clamped to the electrode 130 either mechanically or electrostatically. The processing chamber 140 may, for example, be a vacuum chamber.

A substrate to be processed is inserted into the processing chamber 140.

15 The substrate is processed in the processing chamber by energizing a process gas in the processing chamber into a high density plasma. A source of energy maintains a high density (e.g., 10^{11}-10^{12} ions/cm^3) plasma in the chamber. For example, an antenna 150, such as the planar multiturn coil shown in Figures 2a and 2b, a non-planar multiturn coil, or an antenna having another shape,

20 powered by a suitable RF source and suitable RF impedance matching circuitry inductively couples RF energy into the chamber to provide a high density plasma. However, the plasma can be generated by other sources such as ECR, parallel plate, helicon, helical resonator, etc., type sources. The chamber may include a suitable vacuum pumping apparatus for maintaining the interior of the

25 chamber at a desired pressure (e.g., below 5 Torr, preferably 1-100 mTorr). A dielectric window, such as the planar dielectric window 155 of uniform thickness shown in Figures 2a and 2b or a non-planar dielectric window, is provided between the antenna 150 and the interior of the processing chamber 140 and forms the vacuum wall at the top of the processing chamber 140.

30 A gas supply supplying process gas into the chamber includes a primary gas ring 170 below the dielectric window 155. The gas ring 170 may be

mechanically attached to the chamber housing above the substrate. The gas ring 170 may be made of, for example, aluminum or anodized aluminum.

The gas supply includes a secondary gas ring 160 below the dielectric window 155. The process gas can include one or more gases such as Ar and 5 O_2 delivered into the chamber 140 through orifices in the secondary gas ring 160. Any suitable gas ring may be used as the secondary gas ring 160. The secondary gas ring 160 may be located above the gas ring 170, separated therefrom by an optional spacer 165 formed of aluminum or anodized aluminum, as shown in Figure 2a. Alternatively, although not shown, the 10   secondary gas ring 160 may be located below the gas ring 170, between the gas ring 170 and the substrate 120. Yet another alternative is that the Ar and O_2 may be supplied through orifices in a gas ring 162 connected to the chamber floor, as shown in Figure 2b, with the spacer 165 separating the dielectric window 155 and the primary gas ring 170.

15   The gas supply can further include a plurality of detachable injectors 180 connected to the primary gas ring 170 to direct at least some of a process gas such as SiH_4 or a related silicon-containing gas such as SiF_4, TEOS, and so on, onto the substrate 120. These gases are delivered to the substrate from the injectors 180 through injector exit orifices 187. Additionally, reactant gases 20   may be delivered through orifices in the primary gas ring 170. The injectors may be made of any suitable material such as aluminum, anodized aluminum, quartz or ceramics such as Al_2O_3. Although two injectors are shown in Figures 2a and 2b, any number of injectors may be used. For example, an injector may be connected to each of the orifices on the primary gas ring 170. Preferably, 25   eight to thirty-two injectors are employed on a 200 to 210 mm diameter ring 170 for a 200 mm substrate.

The injectors 180 are located above the plane of the substrate 120, with their orifices at any suitable distance such as, for example, three to ten centimeters from the substrate. The injectors may, according to a preferred 30   embodiment, be spaced inside, near or outside of the substrate periphery, for example zero to five centimeters from the substrate periphery. This helps to

ensure that any potential particle flakes from the injectors will not fall onto the substrate and contaminate it. The injectors may all be the same length or alternatively a combination of different lengths can be used to enhance the deposition rate and uniformity. The injectors are oriented such that at least

5   some of the injectors direct the process gas in a direction which intersects the exposed surface of the substrate.

As opposed to previous gas injection systems designs which rely predominantly on diffusion to distribute process gas above the substrate, the injectors according to one embodiment of the present invention are oriented to

10   inject process gas in a direction which intersects an exposed surface of the substrate at an acute angle. The angle or axis of injection may range from about 15 to < 90 degrees, preferably 15 to 45 degrees from the horizontal plane of the substrate. The angle or axis of injection may be along the axis of the injector or, alternatively, at an angle of up to 90 degrees with respect to the axis

15   of the injector, as shown in Figure 11. The exit orifice diameter of the injectors may be between 0.010 and 0.060 inches, preferably about 0.020 to 0.040 inches. The hollow core of the injectors 180 may be drilled to about twice the diameter of the exit orifices 187 to ensure that sonic flow occurs at the exit orifice and not within the core of the injector. The flow rate of SiH_4 is preferably between

20   25-300 sccm for a 200 mm substrate but could be higher for larger substrates.

Due to the small orifice size and number of injectors and large flowrates of SiH_4, a large pressure differential develops between the gas ring 170 and the chamber interior. For example, with the gas ring at a pressure of >1 Torr, and the chamber interior at a pressure of about 10 mTorr, the pressure differential is

25   about 100:1. This results in choked, sonic flow at the orifices of the injectors. The interior orifice of the injector may also be contoured to provide supersonic flow at the outlet.

Injecting the SiH_4 at sonic velocity inhibits the plasma from penetrating the injectors. This design prevents plasma-induced decomposition of the SiH_4

30   and the subsequent formation of amorphous silicon residues within the gas ring and injector extension tubes.

According to this embodiment, a combination of convective and radiative cooling may be used to limit the chamber wall and gas ring temperatures to preferably less than about 100° C during processing. Alternatively, circulating fluid, preferably at -20 to 100° C, within the chamber walls may be used to

5   control the wall and gas ring temperatures. Because the gas ring temperature is typically maintained below 100° C, no thermal decomposition of SiH_4 is observed within the gas ring. In addition, because the gas ring is effectively an electrically grounded, enclosed metal chamber, no significant electric fields are present within the gas ring, which prevents plasma formation within the ring.

10   The plasma processing system according to this embodiment provides an increased deposition rate and improved uniformity on the substrate, compared to conventional gas distribution systems, by concentrating the silicon-containing process gas above the substrate and by preferentially directing the process gas onto specific regions of the substrate. The following discussion describes

15   experimental data which illustrate the improved capability of the plasma processing system according to the present invention and also briefly describes the relevant theoretical background.

Figure 3a illustrates two exemplary SiO_2 deposition profiles for a plasma processing system in which the gas injectors are located at different positions

20   with respect to the substrate. Both of these cases were obtained at the same deposition conditions (plasma source power = 2000 Watts, electrode bias power = 2000 Watts, SiH_4 flow = 180 sccm, O_2 flow = 300 sccm, pressure = 12 mTorr, 22.5 degrees downward injection angle with respect to the substrate plane) with a non-optimized primary gas ring 170. Case 1 (open boxes) shows

25   experimental data where the (16 circumferential, equally spaced) injector 180 orifices were located about 0.5 cm outside of the substrate periphery, while case 2 (open triangles) shows experimental data where the injector orifices 187 were located about 2 centimeters outside of the substrate periphery. In both of these examples, the injector orifices 187 were located about 5 centimeters above the

30   substrate 120. (Generally speaking, in the plasma processing system according to the present invention, as long as the vertical location of the injector orifices

187 is a few centimeters or more above the substrate 120, the radial location of the injector orifices has a much larger impact on the deposition rate than does the vertical location.)

In case 1, the overall deposition rate is higher, that is 10800
5   Angstroms/minute compared to 9200 Angstroms/minute for case 2. This is because in case 1, the silicon containing process gas is more concentrated over the center of the substrate. However, this increased deposition rate for case 1 comes at the expense of a decreased uniformity, which is 8.1% (1σ) for case 1 compared to 4.1 % for case 2. By concentrating more of the silicon containing
10   process gas onto and above the center of the substrate, the deposition rate on the outer (radial) region of the substrate is not increased in the same proportion as the deposition rate in the center. On the other hand, by positioning the injector orifices 187 further outward, the overall deposition rate is reduced, but the uniformity is improved. Hence, for a constant angle of injection (in this case
15   22.5 degrees) with respect to the substrate, there is a trade-off between deposition rate and uniformity, which occurs as the radial position of the injection point is varied.

The direction of injection from the gas ring 170 can, however, be optimized for each injector, so as to preferentially direct the process gas onto
20   specific regions of the substrate. For example, in optimizing gas ring 170 for case 1, the angle of injection could be adjusted to preferentially direct more silicon-containing gas onto the substrate surface just inside of the substrate periphery. This would lead to an increase in the local deposition rate on the substrate and thereby improve the uniformity.

25   Figure 3b shows experimental data which illustrate the capability for optimizing the deposition rate and uniformity of the plasma processing system according to the present invention by selecting the appropriate angle of injection for a given injection location. Both cases illustrated in Figure 3b were obtained at the same conditions (plasma source power = 2500 Watts, electrode bias
30   power = 2000 W, SiH_4 flow = 250 sccm, O_2 flow = 350 sccm, pressure = 14 mTorr) with identical injection locations (16 injectors, equally spaced

circumferentially, approximately 2 centimeters outside of and approximately 6 centimeters above the substrate), using gas ring 170. In case 3, (open circles) the angle of injection was 0 degrees (parallel to the substrate), while in case 4 (solid squares) the angle of injection was 30 degrees downward (toward the

5   substrate). For case 3, the deposition rate was 10800 Angstroms/minute, while the uniformity was 5.3%, with the deposition rate lowest near the substrate periphery. Similar to the results shown in Figure 3b, the uniformity of case 3 could be improved by moving the injection location more outside of the substrate. This, however, would also result in a substantially decreased

10   deposition rate (in Figure 3a, the uniformity was approximately doubled, but with a 15% loss in deposition rate). By adjusting the injection angle to 30 degrees downward, as in case 4, the deposition onto the outer region of the substrate is increased, and the uniformity is improved to 2.5% while maintaining approximately the same overall deposition rate.

15   This example has demonstrated an unexpected result provided by the plasma processing system according to the present invention of improved deposition uniformity without a loss in deposition rate. This can be used to great advantage to increase the substrate throughput during semiconductor processing.

20   The plasma processing system according to this embodiment provides uniform, directed, rather than diffusive, flux of SiH_4 onto a substrate under typical HDPCVD conditions. Accordingly, consistent deposition uniformities with $1\sigma < 3\%$ are produced in most cases. This is accomplished by carefully superposing the individual injector sprays so that the sum of the injector fluxes

25   at each point on the substrate are nearly equal.

The theoretical basis for increasing the deposition rate near the substrate periphery without significantly reducing the rate near the center of the substrate can be understood from the following discussion. Typically, free jet expansions from sonic nozzles occur in the continuum flow limit, which results in restricted

30   expansions due to the formation of a barrel shock/Mach disk structure. With such restricted expansions, one would not expect to be able to achieve a uniform

flux distribution over the substrate, with a relatively small number of injectors.
According to the present invention, however, the density of the jet and the
chamber ambient are so low that the jet rapidly transitions to the free molecular
flow regime.

5   In the free molecular flow regime, the jet is so rarefied that a shock
structure cannot be established, and the jet simply expands as a Prandtl-Meyer
expansion, with an effectively frozen (constant) temperature and velocity.
Figure 2 illustrates exemplary flow streamlines of the gas jet from an injector.
Referring to Figure 2, in the expansion, the flow streamlines appear to radiate

10   from a point source. The density decreases along each streamline in proportion
to the inverse square of the distance from the source, and the variation of
density from streamline to streamline (with polar angle Θ) is approximately
independent of the polar coordinate R. Thus, for example, at an exemplary flow
rate of 200 sccm SiH_4 from 16 injectors having 0.020 inch diameter orifices, a

15   chamber pressure of 10 mTorr and a gas ring pressure of 3.9 Torr, the total
included angle of the conical expansion is approximately 150 degrees. This
expansion is less divergent and thus more collimated than the cosine distribution
associated with a purely effusive flow.

The centerline density decreases as the square of the distance from the

20   jet exit. That is, the local gas density ρ is given as:

(1) $\rho(R,\Theta = 0) \propto (\rho(R=0,\Theta=0)) / R^2$

where R and Θ are polar coordinates centered at the jet exit, with $\Theta = 0$ defined
as the jet axis. In addition, the density for such as expansion decreases with a
$\cos^2\Theta$ dependence, that is:

25   (2) $\rho(R,\Theta) = \rho(R,0)\cos^2(\pi\Theta/2\phi)$

where ϕ is an empirical constant which depends upon the specific heat ratio for
the injected gas. For example, $\phi = 1.66$ for nitrogen. By combining equation 1
and equation 2 and realizing that the velocity is constant beyond a few jet
diameters, the flux J is determined as a function of position within the

30   expansion as:

(3) $J_{SiH4}(R,\Theta) = \text{constant} \cdot \rho(R,\Theta)$

- 11 -

where J_{SiH4} is the flux of SiH_4.

Figure 5 illustrates qualitatively how a uniform SiH_4 flux may be directed onto the substrate. Referring to Figure 5, assume the flux impinging on the substrate at a point A along a jet centerline is the desired flux. At an off-

5   axis point, B, the radial distance from the axis to the jet is reduced while the streamline angle with respect to the jet centerline is increased. The flux dependence on R and Θ are therefore complementary, and result in a largely uniform flux. That is, the decreased radial distance acts to increase the jet flux, while the increased streamline angle Θ acts to decrease the flux. At an off-axis

10   point C, both the radial position and the streamline angle are increased with respect to point A. This results in a reduced flux at the substrate center from this injector, but this can be compensated for by overlapping spray cones from the other, e.g., 15, injectors around the periphery of the substrate. Similar observations can be made for other points on the substrate. The uniformity is

15   further enhanced because of the large conical expansion of each jet.

The simple analysis above has neglected gas phase collisions. With a mean free path on the order of 1 cm, several gas phase collisions may be expected to occur prior to the SiH_4 molecules reaching the substrate. These collisions act to scatter the directed flux of SiH_4 somewhat, but the jets still

20   maintain a far more directed nature than a purely diffusional source. It is this directional rather than diffusive nature of the plasma processing system according to the present invention that leads to the locally enhanced deposition rate.

Figure 6 illustrates a plasma processing system according to a second

25   embodiment of the present invention. The plasma processing system illustrated in Figure 6 is similar to that shown in Figure 2a, except that the primary ring 170 in Figure 6 is cantilevered and water-cooled. According to this embodiment, reactant gas is delivered through orifices in the gas ring 170 which may be oriented in any direction. Preferably, some of the orifices are directed

30   towards the substrate to enhance the deposition rate.

The water cooling of the gas ring 170 may be accomplished by using two independent welded tubes 185 as shown in Figure 6 or by using a dual tube structure. Alternatively, a water cooling tube (not shown) may be spirally wrapped around the gas ring 170. The water cooling provides thermal control

5   to minimize flaking from the gas ring and also prevents excessive heating of the gas ring due to high density plasma exposure.

Additionally, radiative cooling may be used to limit the chamber wall and gas ring temperatures and prevent thermal decomposition.

Figure 7 illustrates a plasma processing system according to a third

10   embodiment of the present invention. Referring to Figure 7, the plasma processing system may include a cantilevered water-cooled gas ring 170 and injectors 180. The gas ring 170 may also be supported from the chamber floor.

According to this embodiment, reactant gases may be injected toward the substrate in the same manner as described above with regard to the first

15   embodiment. Radiative cooling may be used to limit the chamber wall and gas ring temperatures. Additionally, the lower gas ring may be water-cooled as described above with regard to the second embodiment. Thus, the third embodiment provides uniform, directed deposition onto a substrate as well as thermal control of the gas injection hardware to minimize flaking.

20   Figures 8a-8d illustrate detailed views of exemplary injectors in a plasma processing system according to the present invention. For simplicity of illustration, some elements of the plasma processing system, such as the antenna 150 and the gas rings 160 and 170, are not shown. Figures 8a and 8c depict examples of orientations of the injector 180 with respect to the substrate 120.

25   Figure 8a shows the injector 180 oriented approximately 45 degrees from the horizontal plane of the substrate 120. Figure 8c shows an alternative but less optimal orientation of the injector 180 at 90 degrees from the horizontal plane of the substrate 120. Although not shown, preferably the axis of injection (i.e., gas flow direction) is 15 to 45 degrees from the horizontal plane of the substrate

30   120.

Figures 8b and 8d illustrate in detail the injector 180 shown in Figures

8a and 8c, respectively. As illustrated in Figures 8b and 8d, the core of the

injector is larger than the diameter of the exit orifice 187 of the injector. This

ensures that sonic flow occurs at the exit orifice and not within the core of the

5   injector.

Figures 9a-9c and 10a-10c illustrate detailed views of exemplary

injectors and gas rings according to the present invention. Figure 9a illustrates a

top view of the gas rings 160 and 170 and the injector 180. Figure 9b

illustrates a bottom view of the gas rings 160 and 170 and the injector 180.

10   Figure 9c illustrates a detailed top view of the injector 180.

Similarly, Figures 10a and 10b illustrate a top view and a bottom view,

respectively, of the gas rings 160 and 170 and the injector 180. Figure 10c

illustrates a detailed top view of the injector 180. Figures 10a, 10b and 10c are

similar to Figures 9a, 9b, and 9c, respectively, except that the shapes of the gas

15   outlets on the lower gas ring 170 are different.

Figure 11 illustrates a detailed view of an exemplary injector according

to the present invention. Figure 11 shows exemplary dimensions of an injector

180 that may, for example, be in units of inches. As shown in Figure 11, the

angle of injection from the exit orifice 187 with respect to the injection axis

20   may range from 0 to 90 degrees. As in Figures 8b and 8d, it is apparent from

Figure 11 that the core of the injector 180 is larger than the diameter of the exit

orifice 187 of the injector. This ensures that sonic flow occurs at the exit

orifice and not within the core of the injector. The exemplary dimensions of an

injector 180 are shown in Figure 9 for purposes of illustration. The injector

25   according to the present invention is not, however, limited to these dimensions.

The dimensions may be selected as desired to be any amount, depending on the

application.

While the foregoing gas injection system has been described with

reference to a high density plasma CVD system, it could be used for other

30   processes such as etching. It may, for example, be used for plasma etching in

semiconductor applications which are predominately chemical etching systems, such as chlorine etching of aluminum.

The foregoing has described the principles, preferred embodiments and modes of operation of the present invention. However, the invention should not

5   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 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.   A plasma processing system comprising:

a plasma processing chamber;

a substrate holder supporting a substrate within the processing

5   chamber;

a dielectric member having an interior surface facing the substrate

holder, wherein the dielectric member forms a wall of the processing chamber;

a gas supply including orifices supplying process gas into the

chamber, at least some of the orifices orienting the process gas along an axis of

10   injection which intersects an exposed surface of said substrate at an acute angle;

and

an RF energy source which inductively couples RF energy

through the dielectric member and into the chamber to energize the process gas

into a plasma state to process the substrate.

15   2.   The system of Claim 1, wherein the system is a chemical vapor

deposition system or a plasma etching system.

3.   The system of Claim 1, wherein said RF energy source comprises

a planar or non-planar coil.

4.   The system of Claim 2, wherein the gas supply supplies a

20   halogen and/or oxygen-containing gas or gases for plasma etching, stripping or

cleaning the substrate.

5.   The system of Claim 1, wherein said gas supply comprises a

primary gas ring supplying a gas or gas mixture into said chamber such that at

least some of the gas or gas mixture is directed towards said substrate.

6.   The system of Claim 5, wherein said gas supply further comprises a secondary gas ring supplying an additional gas or gas mixture into said chamber.

7.   The system of Claim 5, wherein said gas supply further comprises injectors connected to said primary gas ring, the injectors injecting said gas or gas mixture into said chamber such that at least some of the gas or gas mixture is directed toward said substrate.

8.   The system of Claim 7, wherein the injectors are located near or outside of the substrate periphery.

9.   The system of Claim 7, wherein said injectors inject said gas or gas mixture into said chamber at an angle over 15 degrees with respect to the exposed surface of said substrate and/or the injectors form the gas or gas mixture into a plurality of gas flows which overlap each other in an area above the substrate.

10.   The system of Claim 5, wherein said primary gas ring is cantilevered.

11.   The system of Claim 5, further comprising a cooling mechanism cooling said primary gas ring during processing.

12.   The system of Claim 11, wherein the cooling mechanism comprises means for supplying an electrically non-conductive cooling liquid to prevent excessive heating during processing of the substrate.

13.   The system of Claim 7, wherein the injectors inject at least some of the gas or gas mixture at a sonic or supersonic velocity.

14.   The system of Claim 1, wherein the gas supply supplies a silicon-containing gas, and substrates are consecutively processed in the processing chamber by contacting the substrates with the plasma gas and depositing a silicon-containing layer on each of the substrates.

5   15.   The system of Claim 1, wherein some of the orifices supply the process gas in a direction which does not intersect the exposed surface of the substrate.

16.   A method of depositing a layer on a substrate comprising:

        placing a substrate on a substrate holder in a processing chamber,
10   wherein an interior surface of a dielectric member forming a wall of the process chamber faces the substrate holder;

        supplying process gas into the processing chamber from a gas supply including orifices, at least some of the orifices orienting the process gas along an axis of injection which intersects an exposed surface of the substrate at
15   an acute angle; and

        energizing the process gas into a plasma state by inductively coupling RF energy through the dielectric member into the processing chamber, the process gas being plasma phase reacted with the exposed surface of the substrate such that a layer of material is deposited on the exposed surface.

20   17.   The method of Claim 16, wherein said step of supplying a gas comprises the steps of:

        supplying a gas or gas mixture from a primary gas ring, wherein at least some of said gas or gas mixture is directed toward said substrate.

18.   The method of Claim 17, wherein said step of supplying a gas
25   further comprises the steps of:

        supplying an additional gas or gas mixture from a secondary gas ring.

- 18 -

19.   The method of Claim 17, wherein injectors are connected to said primary gas ring, the injectors injecting at least some of said gas or gas mixture into said chamber and directed toward said substrate.

20.   The method of Claim 19, wherein the injectors are located near or outside of the substrate periphery.

21.   The method of Claim 19, wherein said injectors inject at least some of said gas or gas mixture into said chamber at an angle over 15 degrees with respect to the exposed surface of said substrate.

22.   The method of Claim 16, wherein the process gas is energized by an RF antenna in the form of a planar coil.

23.   The method of Claim 16, wherein the process gas is energized by an RF antenna in the form of a non-planar coil.

24.   The method of Claim 17, wherein said primary gas ring is cantilevered, and the method further comprises a step of cooling the primary gas ring during processing.

25.   The method of Claim 24, wherein said step of cooling comprises passing an electrically non-conductive cooling liquid in heat transfer contact with the primary gas ring to prevent excessive heating of the primary gas ring during processing of the substrate.

26.   The method of Claim 22, wherein the layer of material deposited on the substrate comprises a silicon-containing layer.

27.   The method of Claim 16, wherein substrates are consecutively processed in the processing chamber by contacting the substrates with the plasma gas.

28.   The method of Claim 16, wherein some of the orifices supply the process gas in a direction which does not intersect the exposed surface of the substrate.

1/8

FIG. 1

FIG. 2a

2/8

FIG. 2b

FIG. 4

FIG. 5
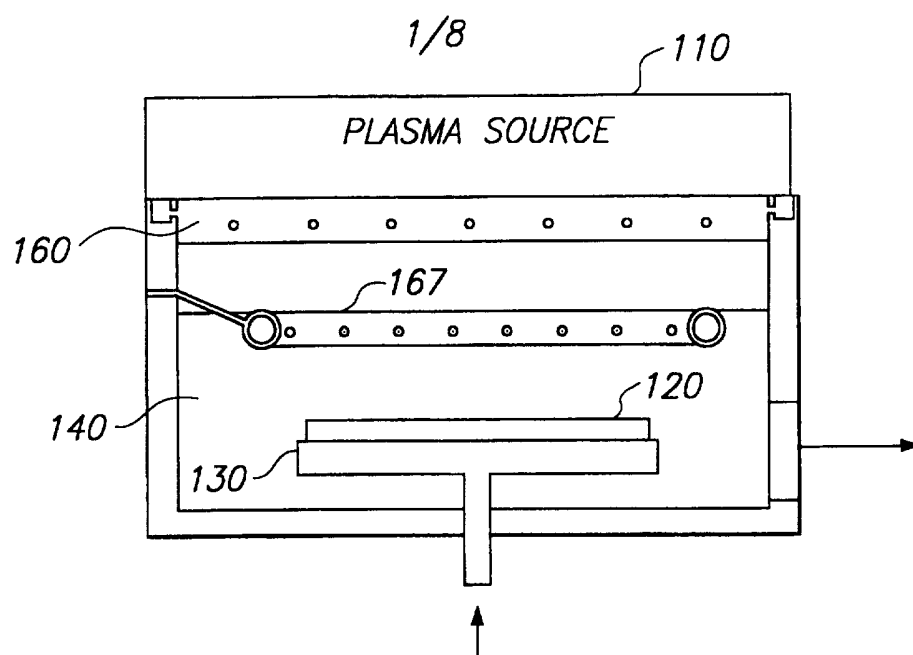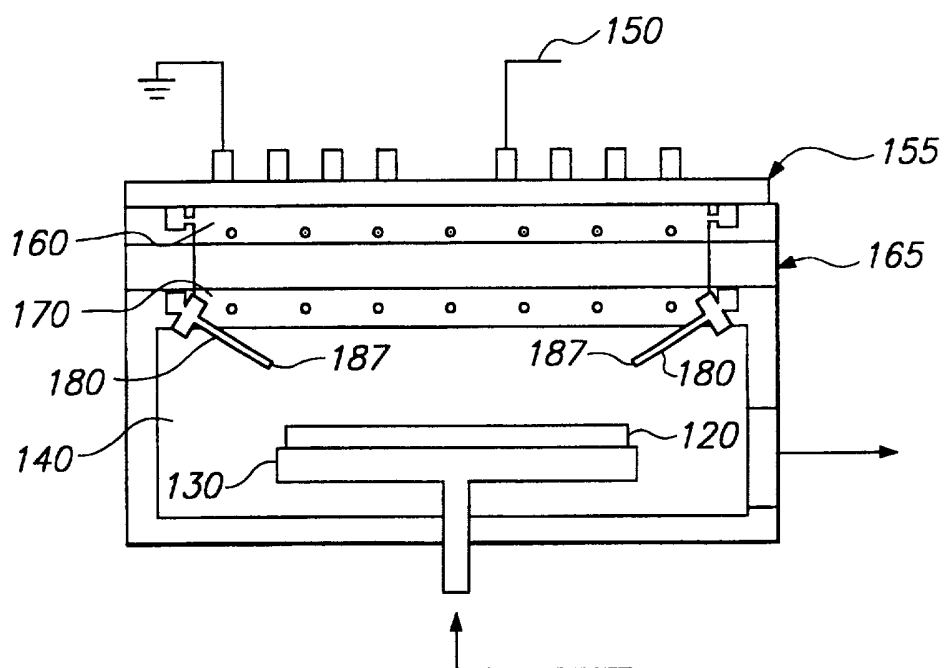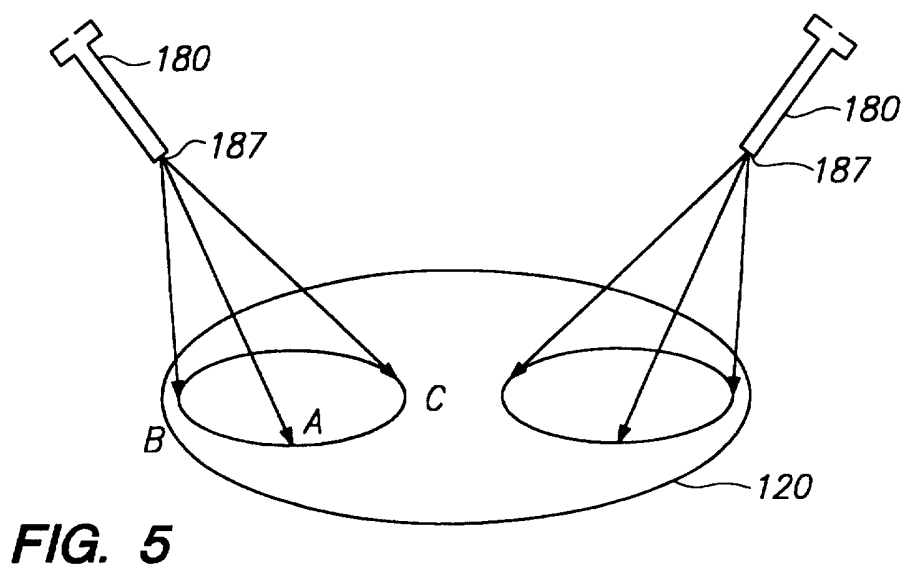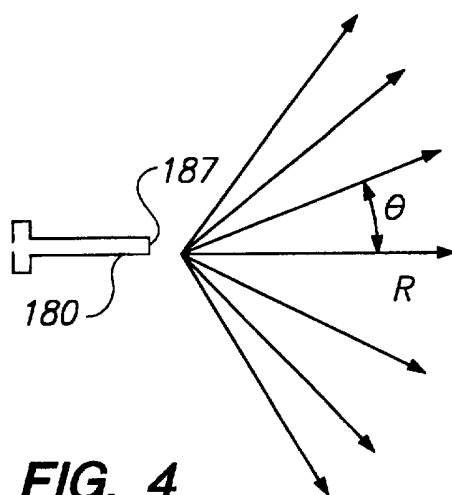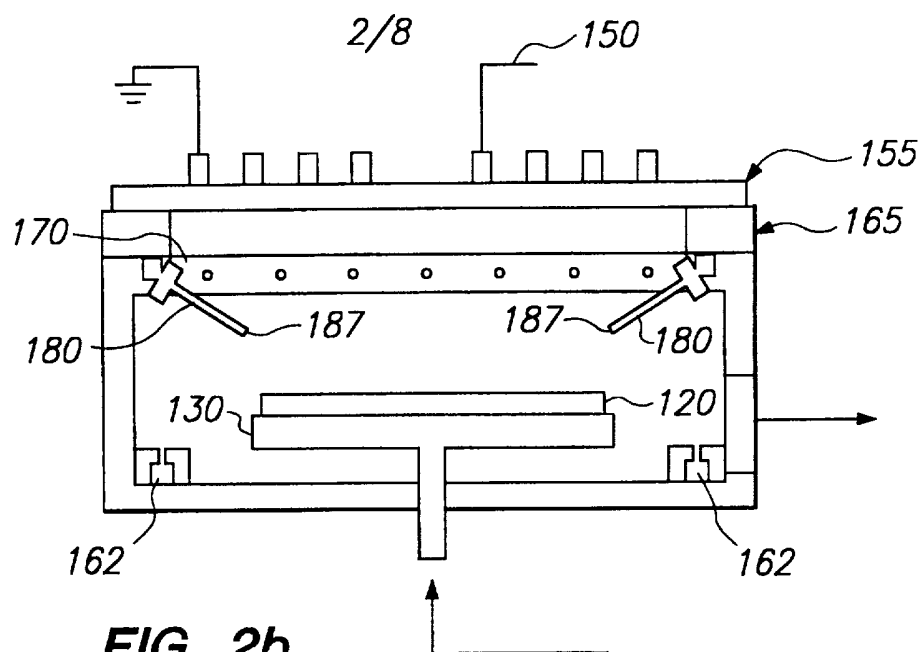
3/8

COMPARISON OF RATE FOR DIFFERENT INJECTOR LOCATIONS
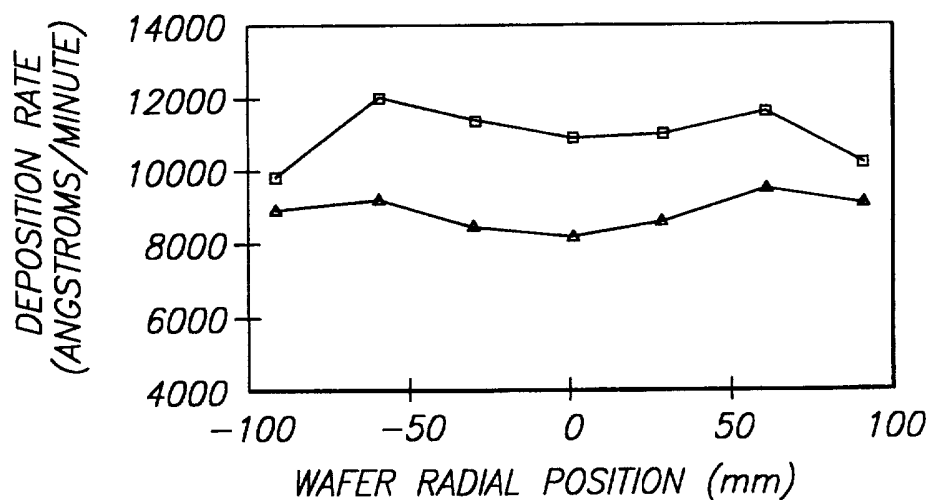
FIG. 3a

GAS INJECTION COMPARISON (0 DEG VS 30 DEG DOWN)

FIG. 3b

4/8

FIG. 6

FIG. 7
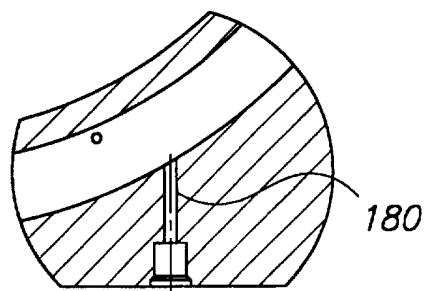
FIG. 8a

FIG. 8b

FIG. 8c

FIG. 8d
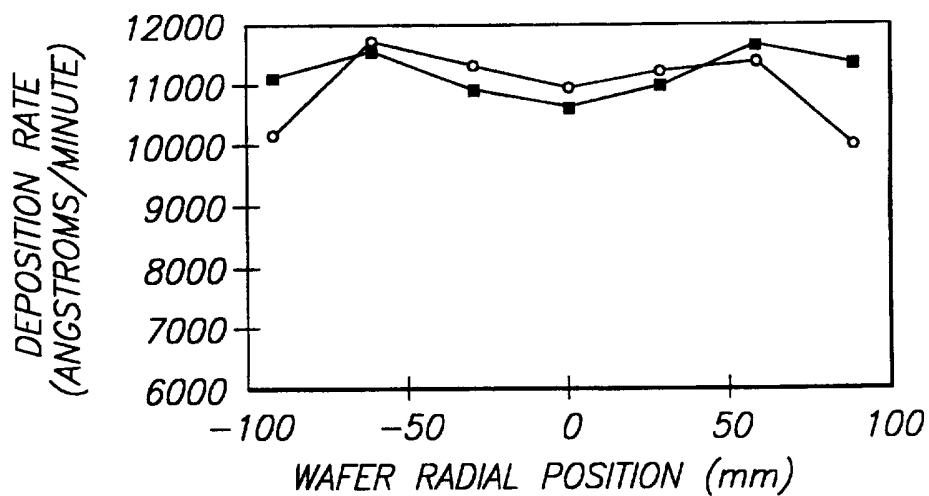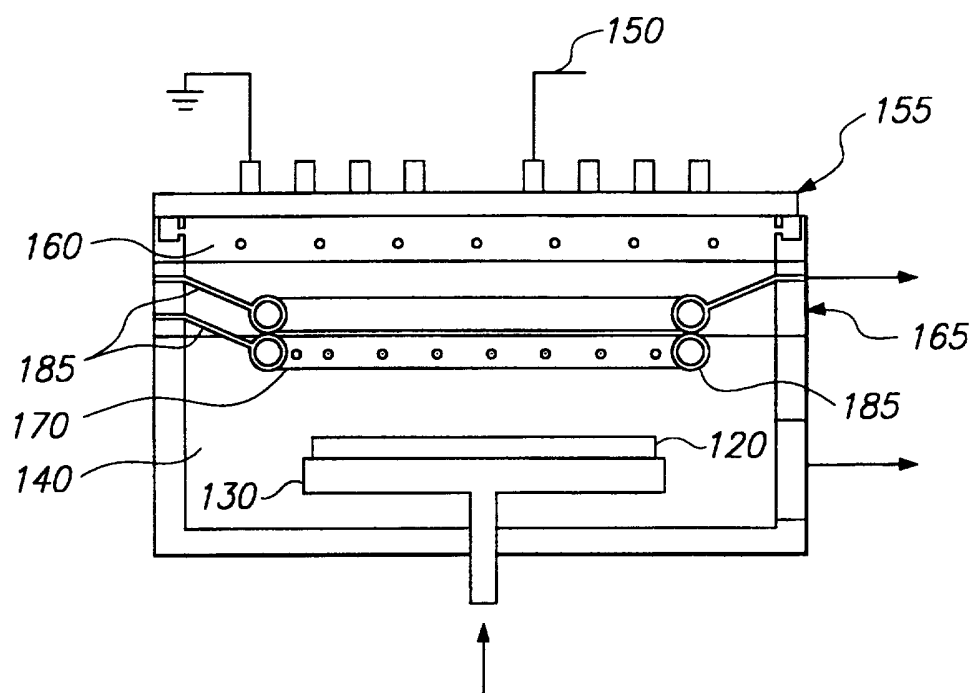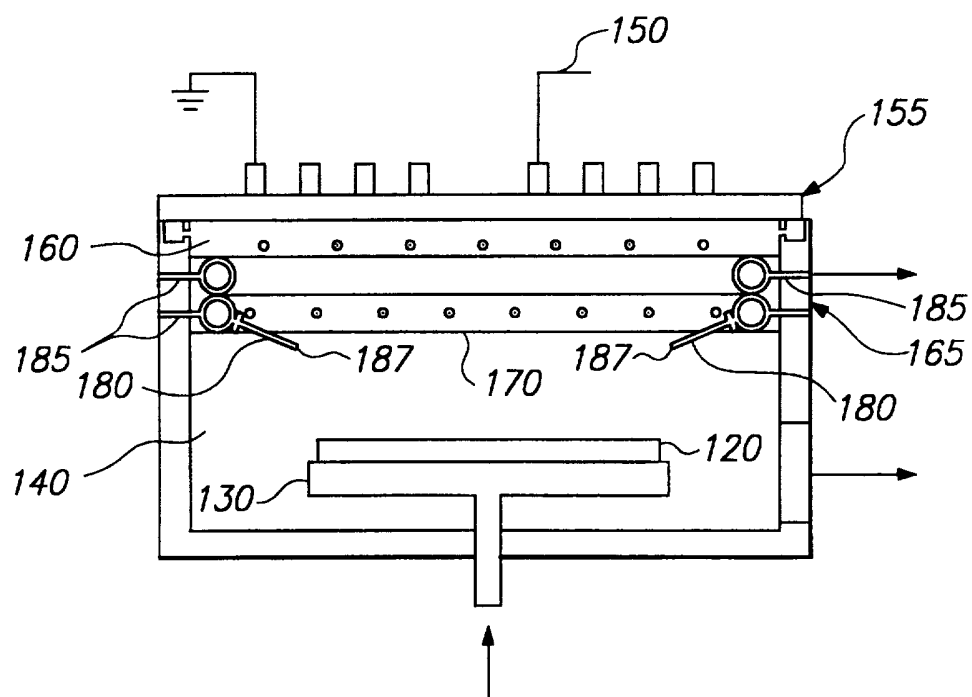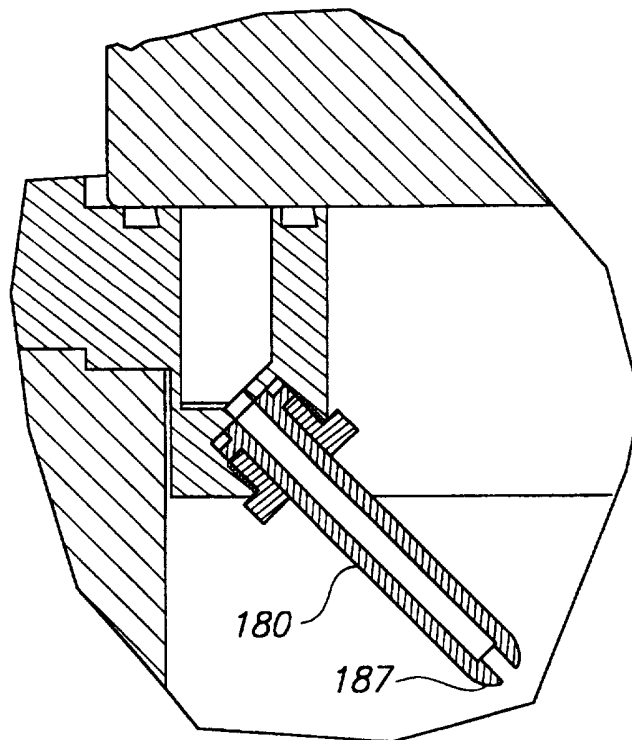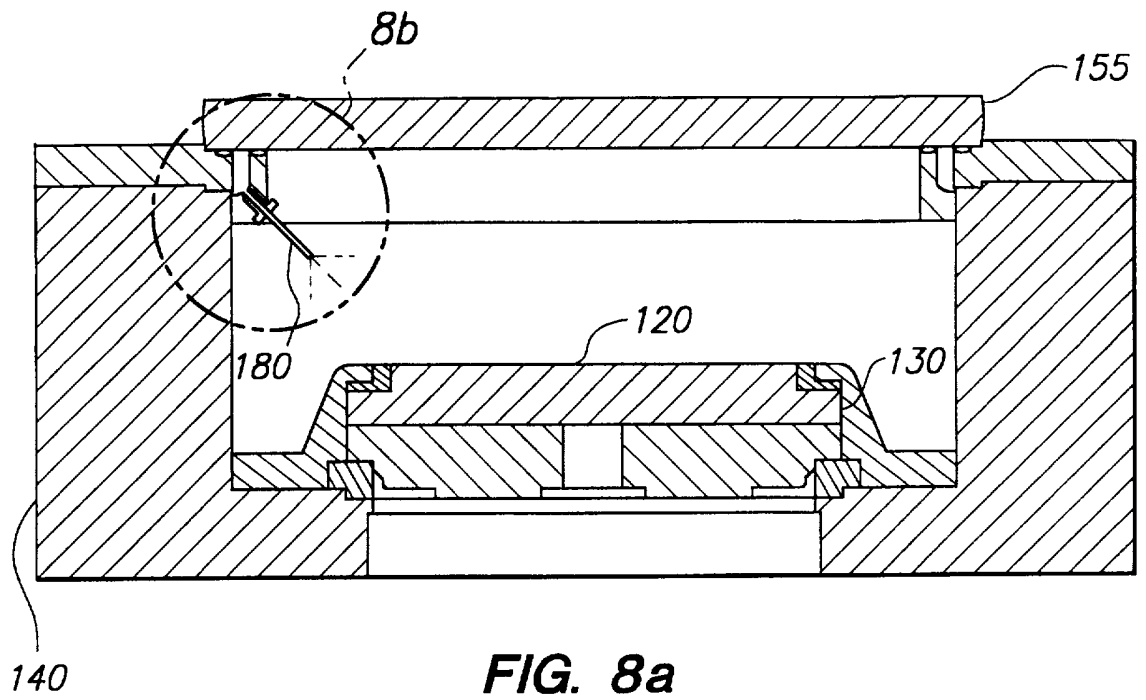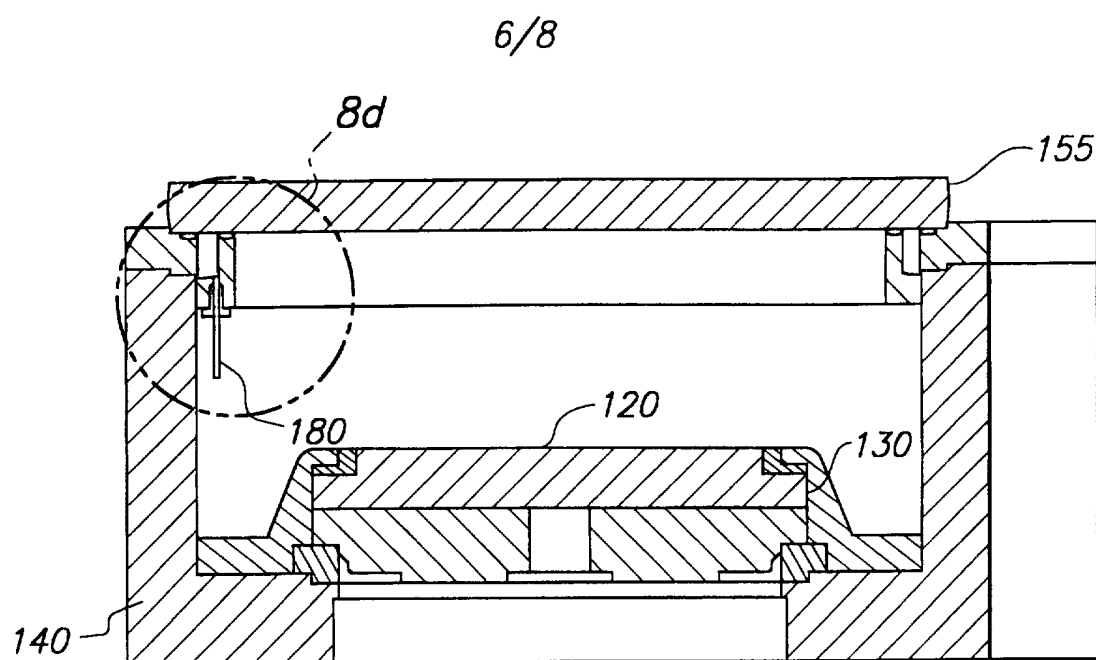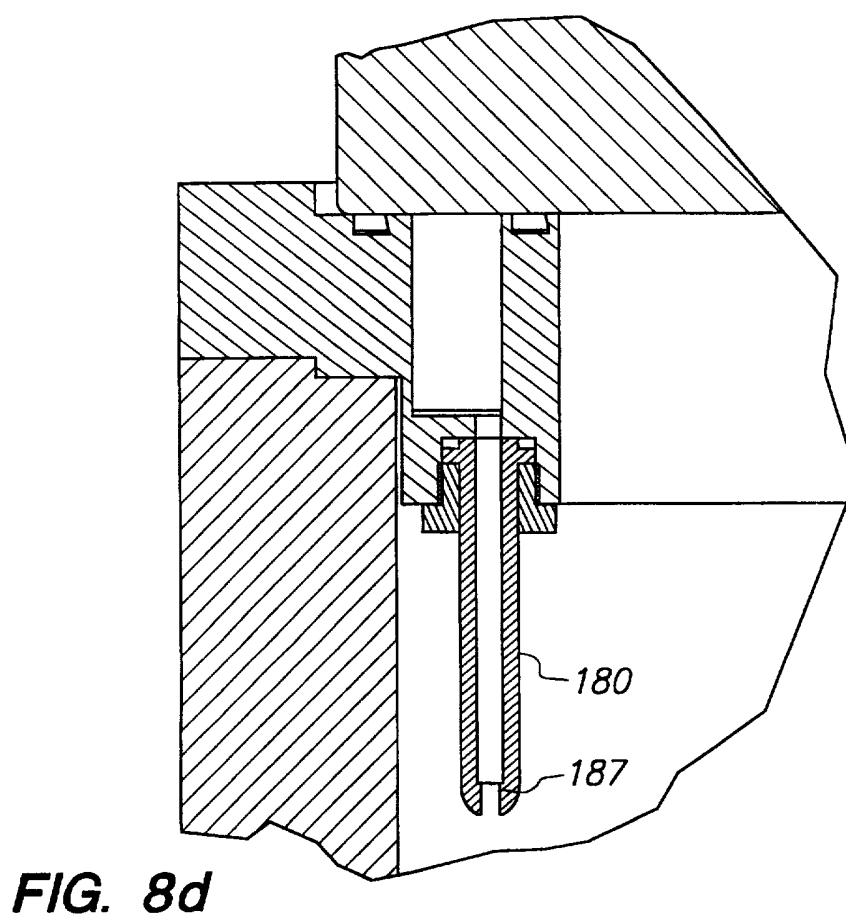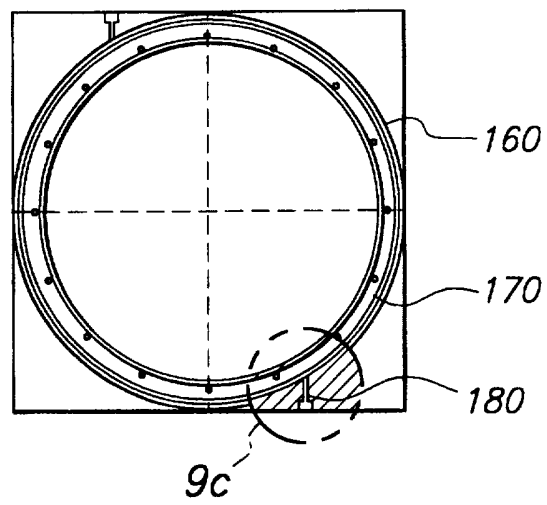
FIG. 9a
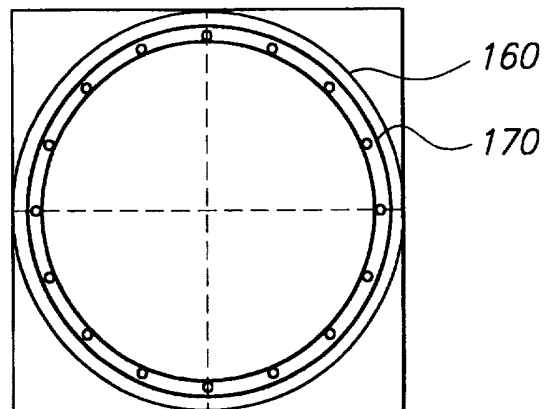
FIG. 9b

FIG. 9c
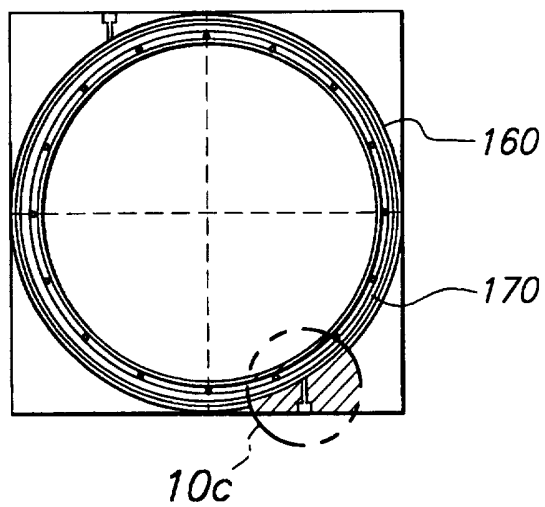
FIG. 10a
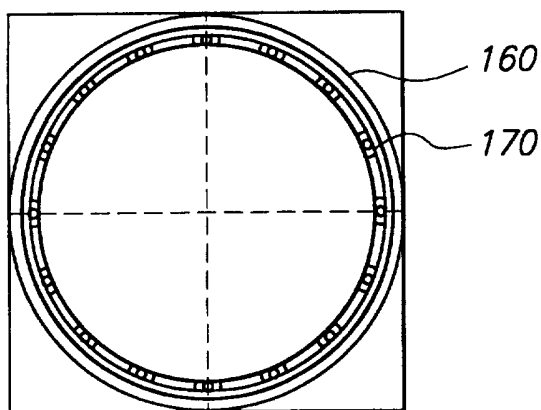
FIG. 10b

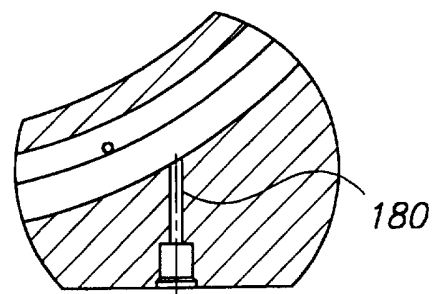FIG. 10c

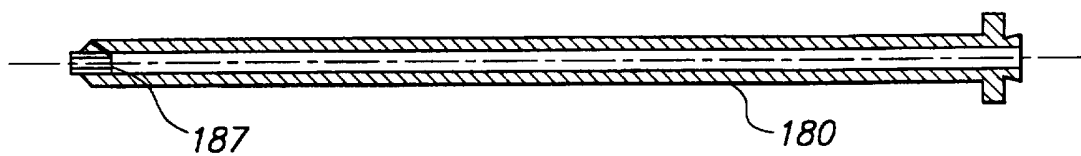FIG. 11

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   C23C16/50   H01J37/32   C23C16/44

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   C23C   H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 522 934 A (SUZUKI AKIRA ET AL) 4 June 1996 see column 10, line 58 - column 11, line 20; figures 12,13 ---	1-3,16, 17
X	EP 0 709 875 A (APPLIED MATERIALS INC) 1 May 1996 see column 4, line 41 - column 5, line 19; figures 1,2 ---	1-3,16, 17
A	EP 0 520 519 A (APPLIED MATERIALS INC) 30 December 1992 see page 17, line 41 - page 18, line 11 ---	11,12, 24,25
A	EP 0 641 013 A (APPLIED MATERIALS INC) 1 March 1995 see column 8, line 8 - column 10, line 24; claims 1,14,15; figure 6 -----	13

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

16 September 1997

Date of mailing of the international search report

3 0. 09. 97

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+ 31-70) 340-3016

Authorized officer

Patterson, A

Form PCT ISA 210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5522934 A	04-06-96	JP 8017748 A JP 8013169 A	19-01-96 16-01-96
EP 0709875 A	01-05-96	US 5597439 A JP 8239775 A	28-01-97 17-09-96
EP 0520519 A	30-12-92	JP 5206072 A US 5556501 A US 5574410 A US 5572170 A US 5392018 A EP 0552490 A EP 0552491 A	13-08-93 17-09-96 12-11-96 05-11-96 21-02-95 28-07-93 28-07-93
EP 0641013 A	01-03-95	US 5614055 A EP 0794553 A JP 7169703 A	25-03-97 10-09-97 04-07-95