US 20060236934A1

(19) United States

(12) Patent Application Publication

Choi et al.

(10) Pub. No.: US 2006/0236934 A1

(43) Pub. Date: Oct. 26, 2006

(54) **PLASMA UNIFORMITY CONTROL BY GAS DIFFUSER HOLE DESIGN**

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(21) Appl. No.: **11/473,661**

(22) Filed: **Jun. 22, 2006**

Related U.S. Application Data

(63) Continuation of application No. 10/889,683, filed on Jul. 12, 2004.

(60) Provisional application No. 60/570,876, filed on May 12, 2004.

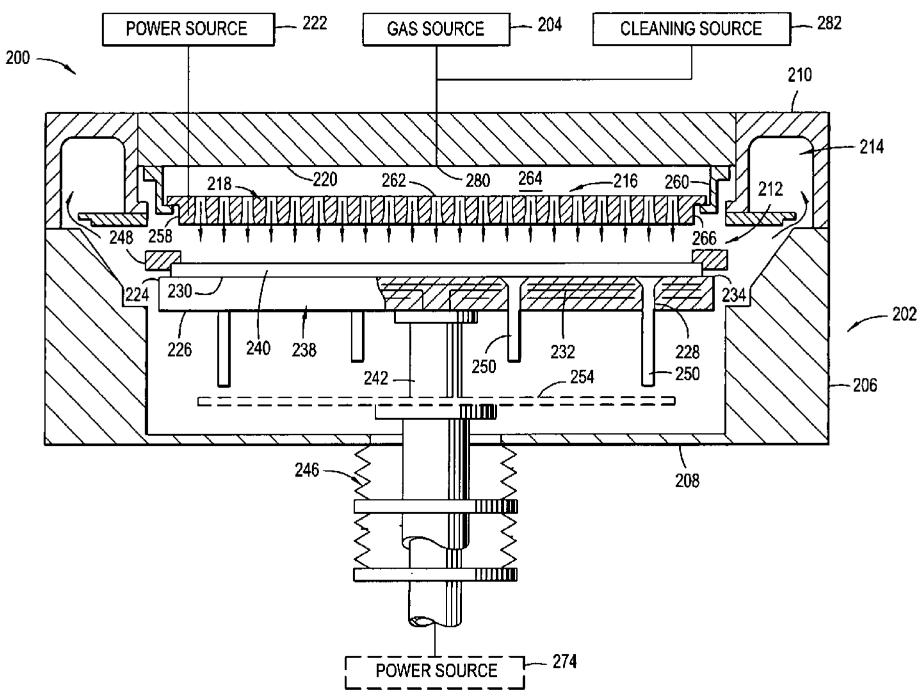
Publication Classification

(51) **Int. Cl.**
C23F 1/00 (2006.01)
C23C 16/00 (2006.01)

(52) **U.S. Cl.** .... **118/723 R**; 156/345.34

(57) **ABSTRACT**

Embodiments of a gas diffuser plate for distributing gas in a processing chamber are provided. The gas distribution plate includes a diffuser plate having an upstream side and a downstream side, and a plurality of gas passages passing between the upstream and downstream sides of the diffuser plate. The gas passages include hollow cathode cavities at the downstream side to enhance plasma ionization. The depths, the diameters, the surface area and density of hollow cathode cavities of the gas passages that extend to the downstream end can be gradually increased from the center to the edge of the diffuser plate to improve the film thickness and property uniformity across the substrate. The increasing diameters, depths and surface areas from the center to the edge of the diffuser plate can be created by bending the diffuser plate toward downstream side, followed by machining out the convex downstream side. Bending the diffuser plate can be accomplished by a thermal process or a vacuum process. The increasing diameters, depths and surface areas from the center to the edge of the diffuser plate can also be created computer numerically controlled machining. Diffuser plates with gradually increasing diameters, depths and surface areas of the hollow cathode cavities from the center to the edge of the diffuser plate have been shown to produce improved uniformities of film thickness and film properties.



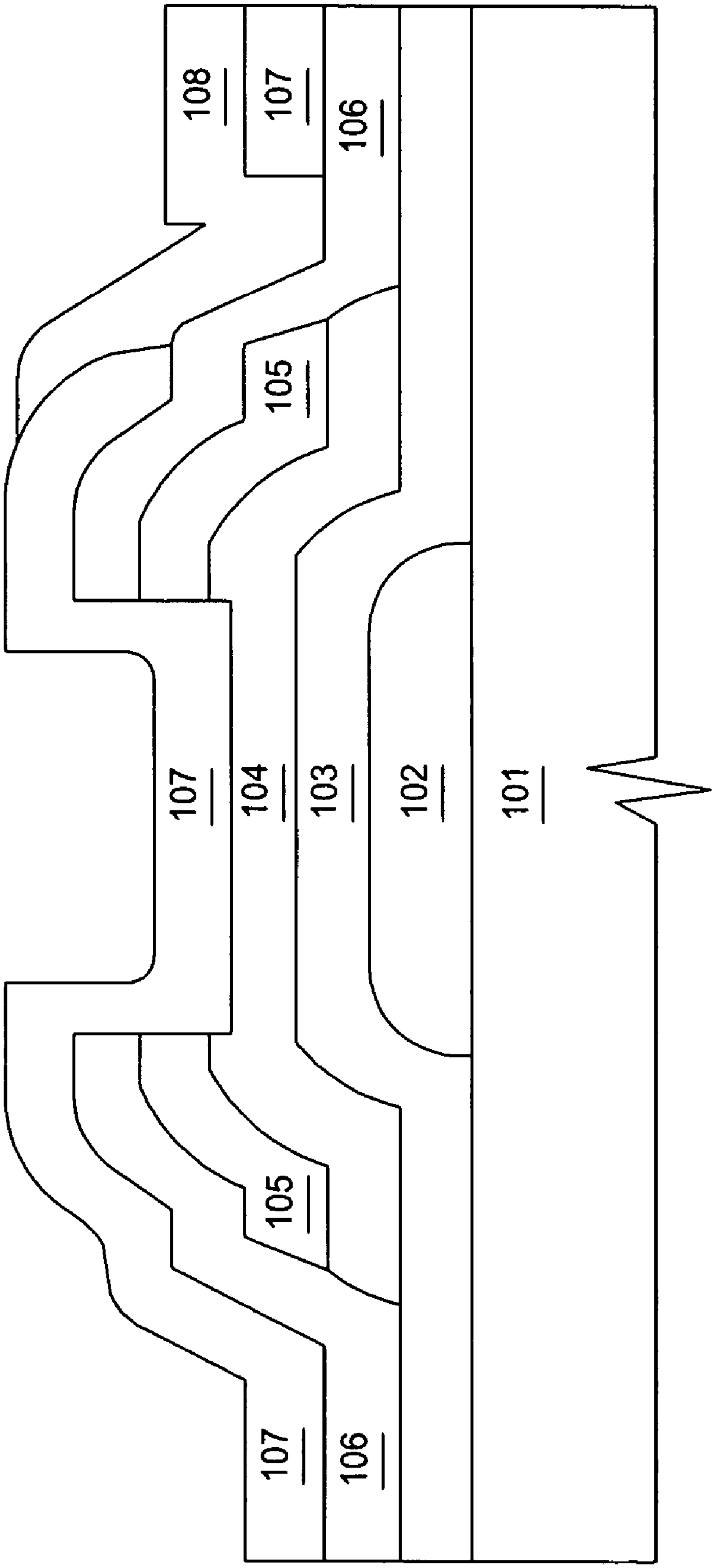
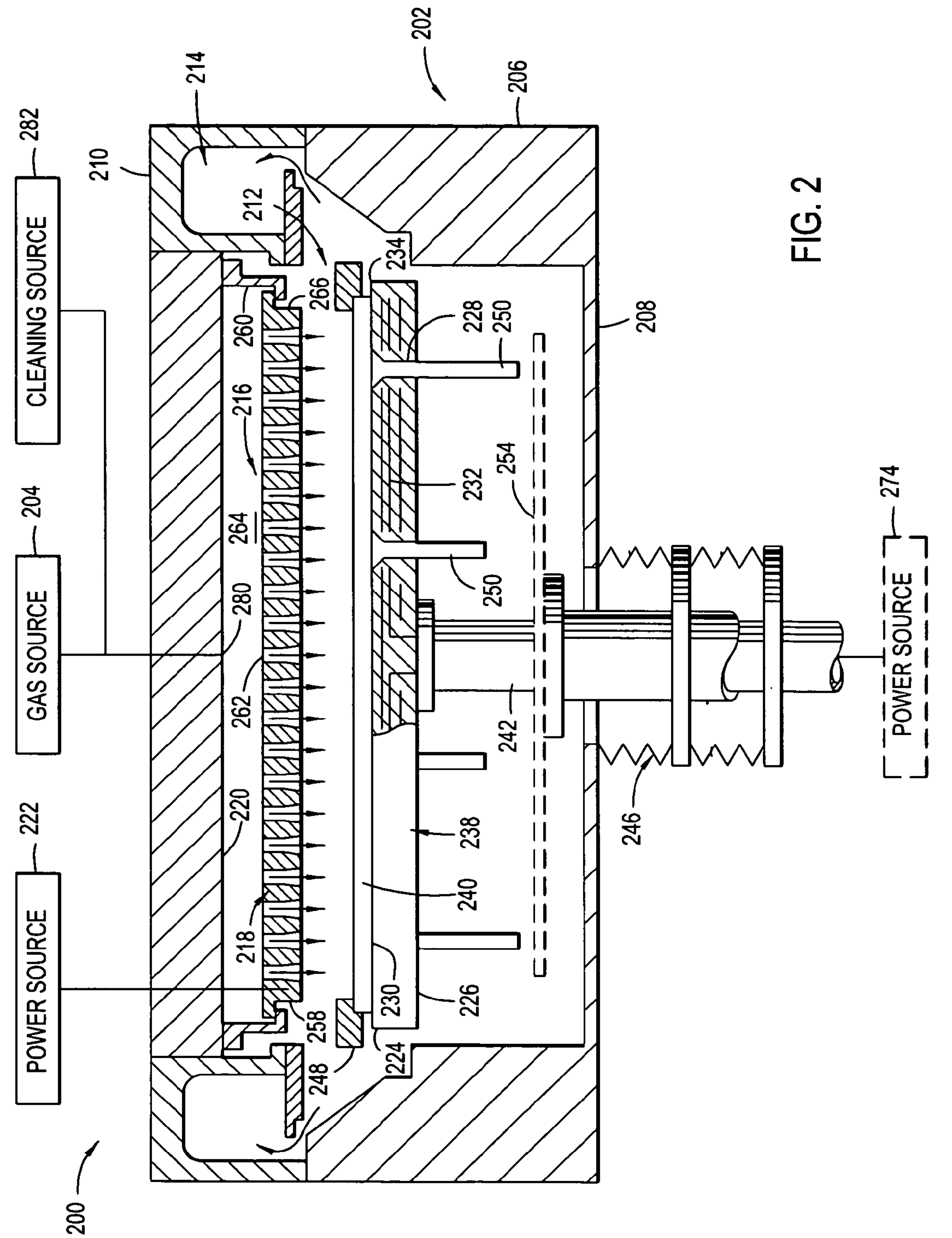


FIG. 1


CLEANING SOURCE
GAS SOURCE
POWER SOURCE
POWER SOURCE
200
202
204
206
208
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212
214
216
218
220
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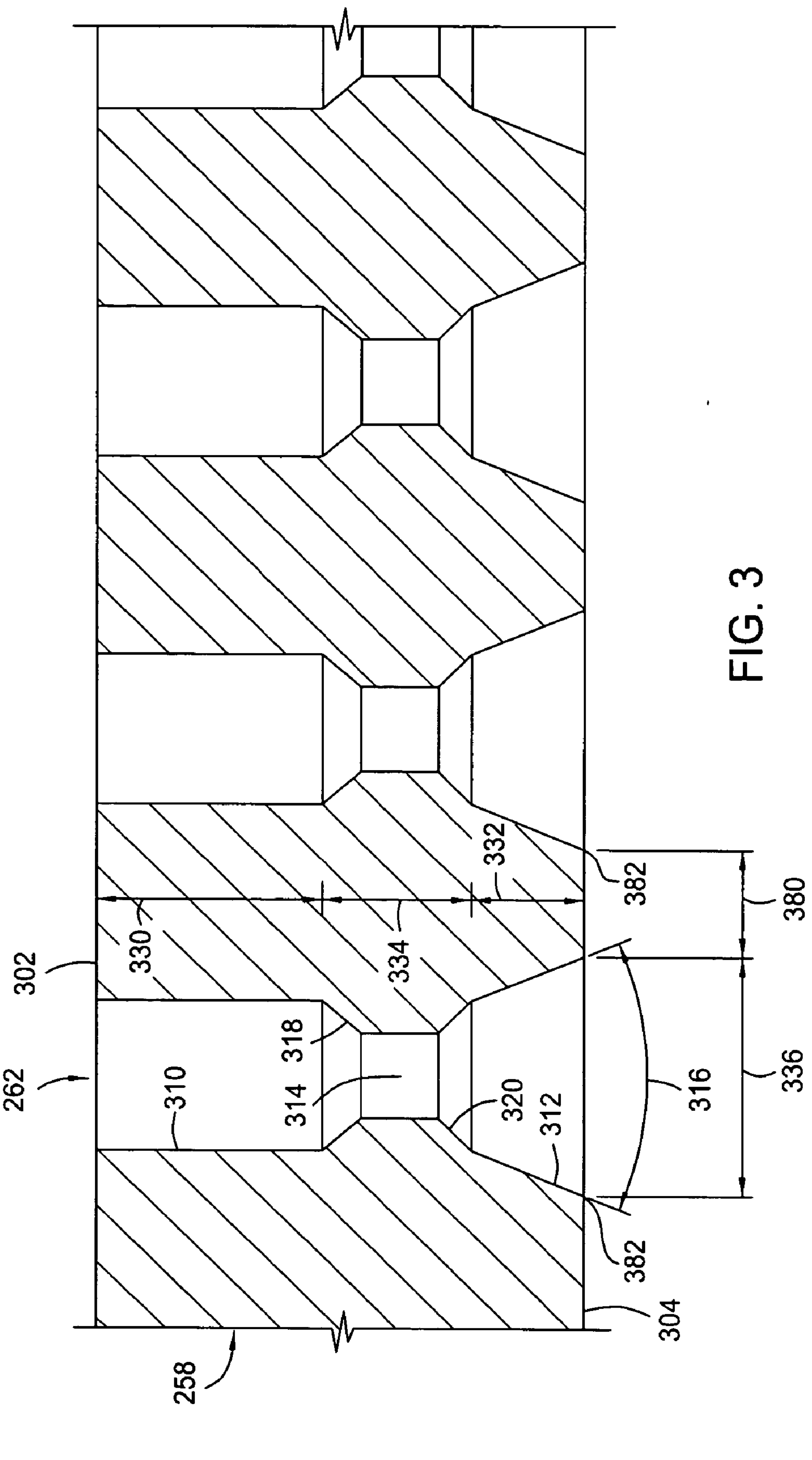
224
226
228
230
232
234
238
240
242
246
248
250
250
254
258
260
262
264
266
274
280
282

FIG. 2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334
332
382
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336
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318
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312
382
304

FIG. 3

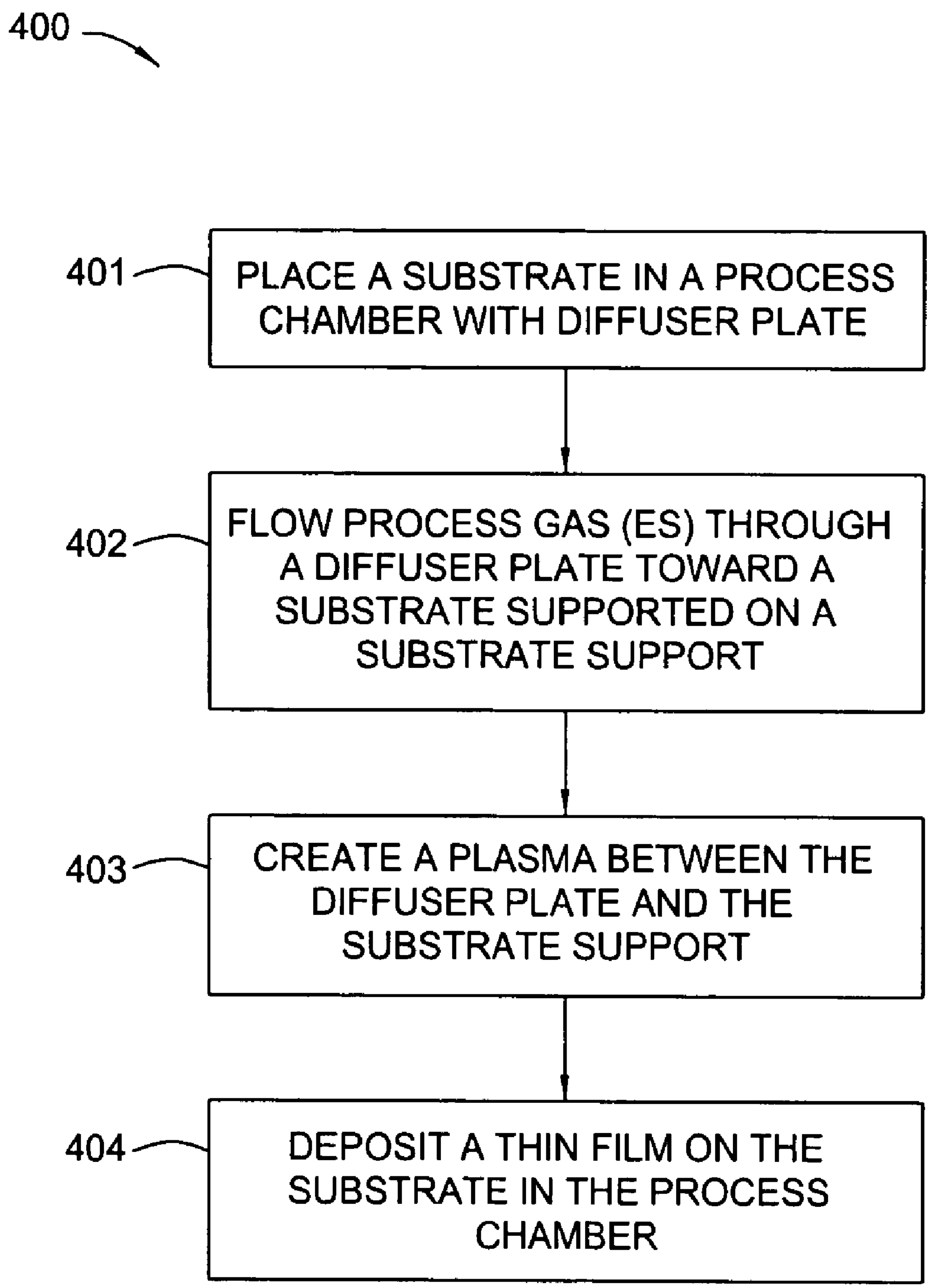
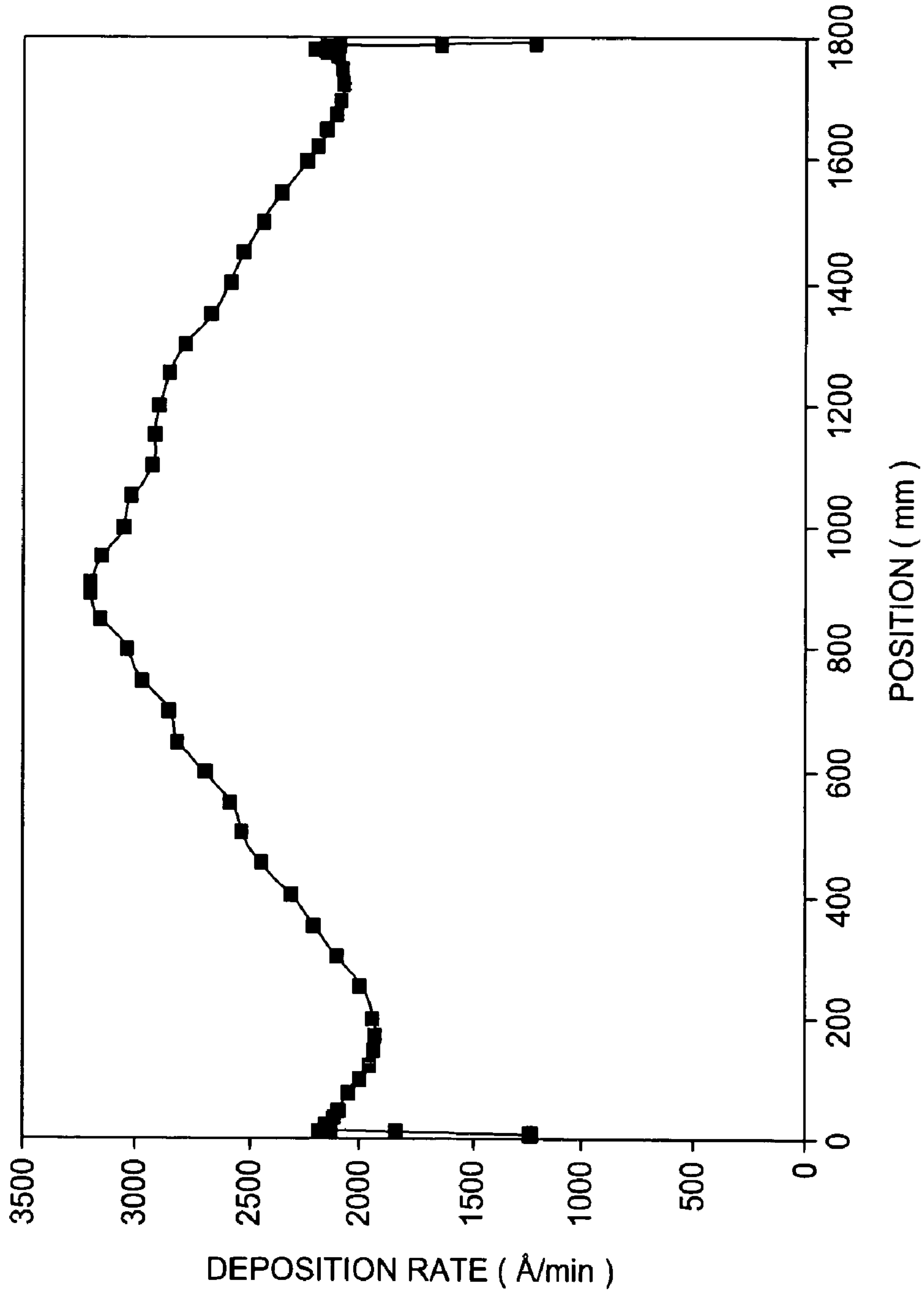

400
401
PLACE A SUBSTRATE IN A PROCESS CHAMBER WITH DIFFUSER PLATE
402
FLOW PROCESS GAS (ES) THROUGH A DIFFUSER PLATE TOWARD A SUBSTRATE SUPPORTED ON A SUBSTRATE SUPPORT
403
CREATE A PLASMA BETWEEN THE DIFFUSER PLATE AND THE SUBSTRATE SUPPORT
404
DEPOSIT A THIN FILM ON THE SUBSTRATE IN THE PROCESS CHAMBER

FIG. 4A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3500
3000
2500
2000
1500
1000
500
0
POSITION (mm)
0
200
400
600
800
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1200
1400
1600
1800

FIG. 4B

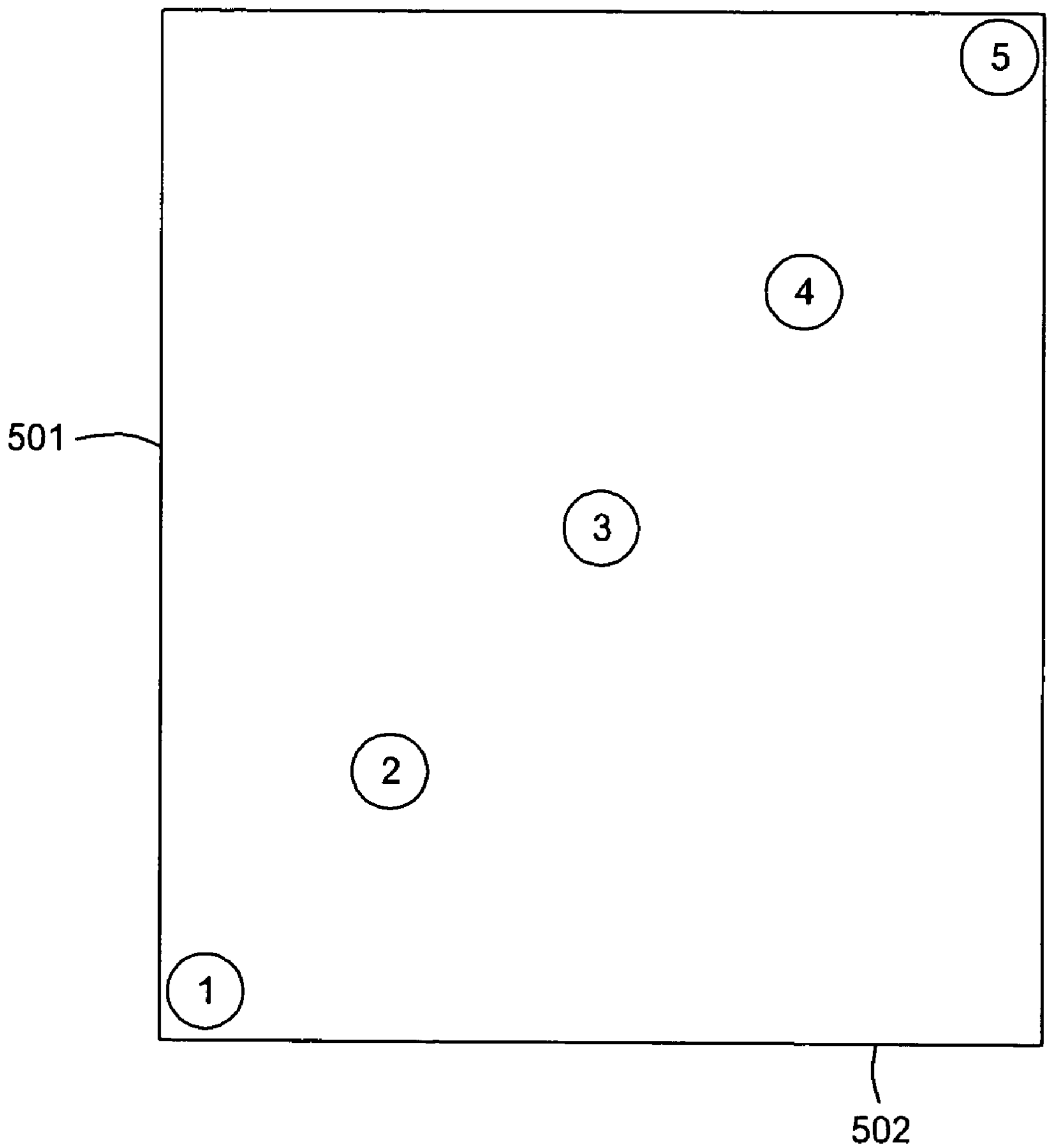


FIG. 5

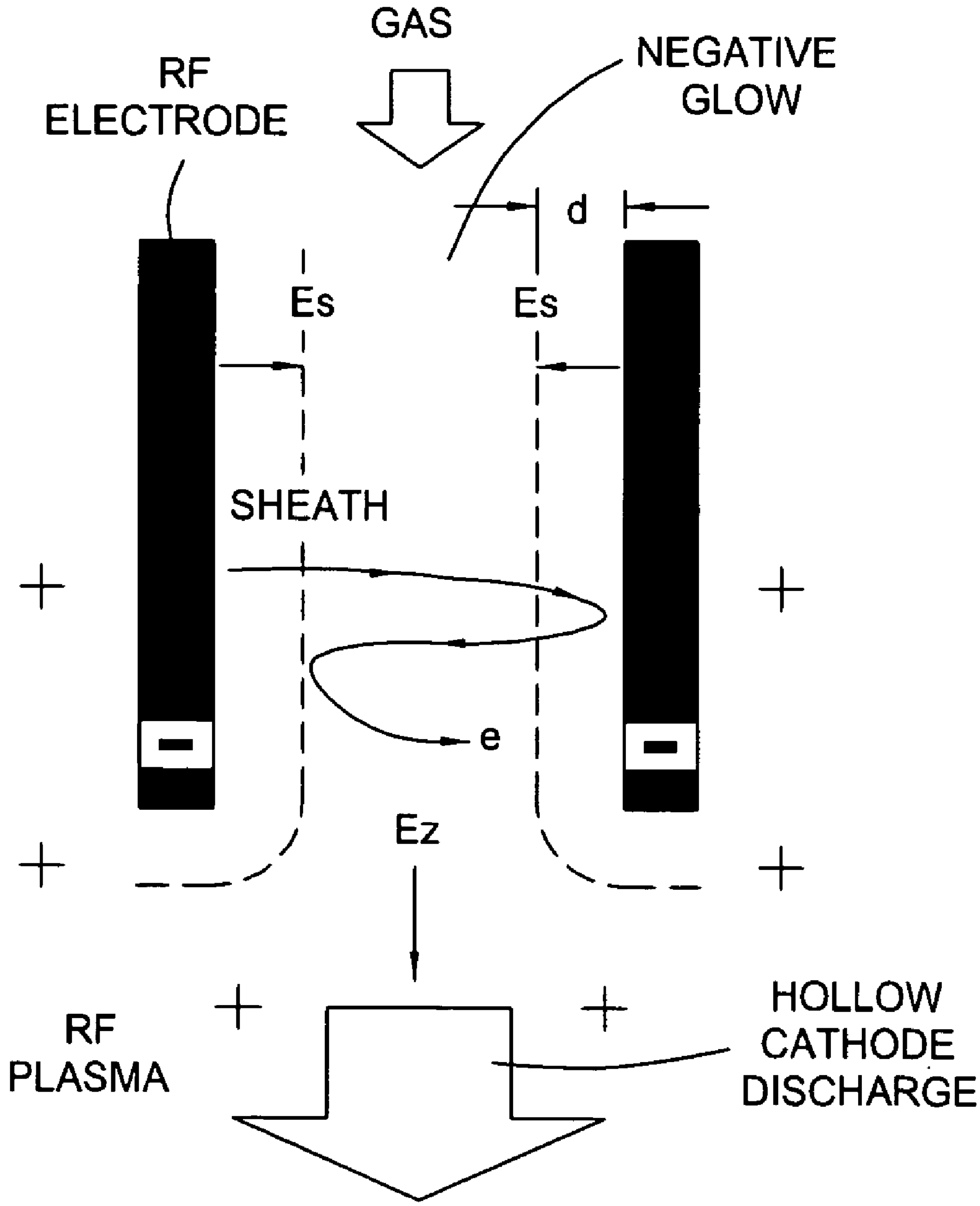


FIG. 6A
(PRIOR ART)

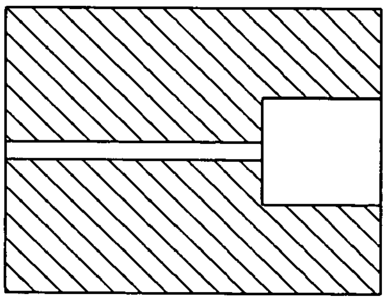


FIG. 6B

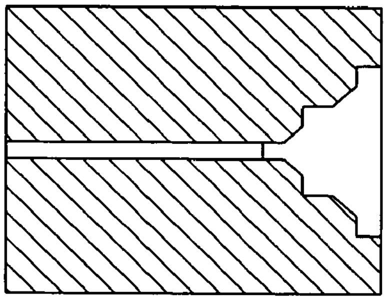


FIG. 6C

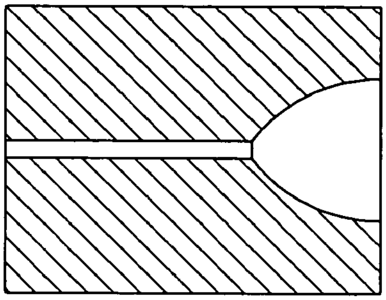


FIG. 6D

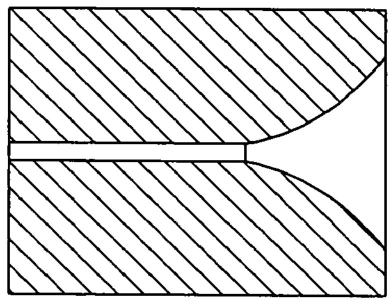


FIG. 6E

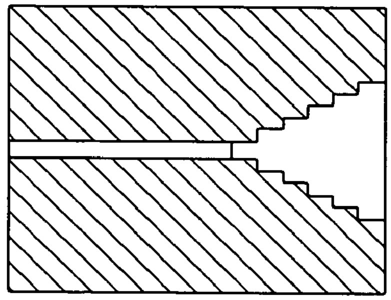


FIG. 6F

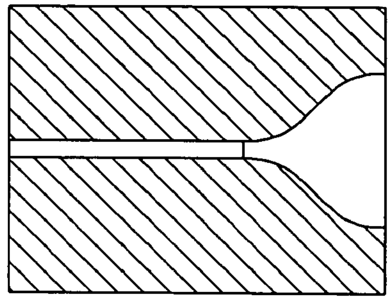


FIG. 6G

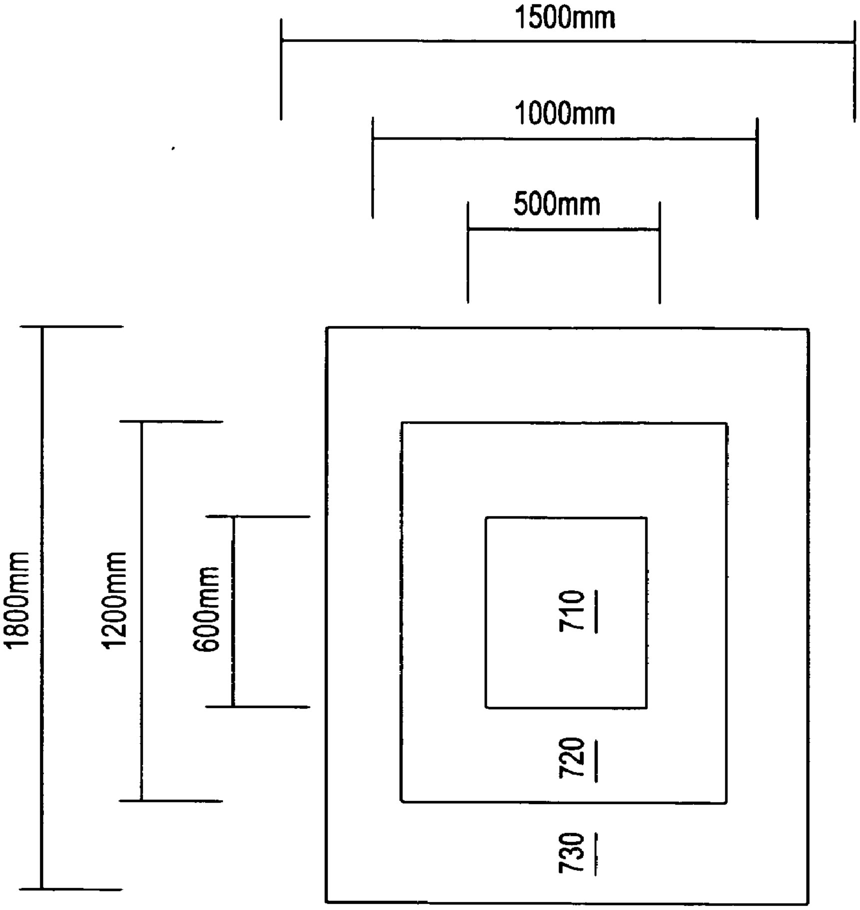


FIG. 7E

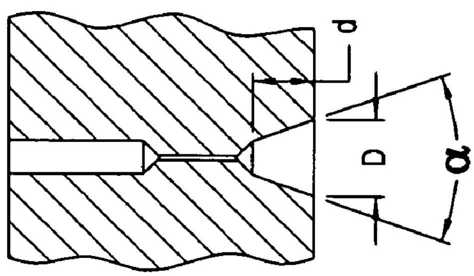


FIG. 7A

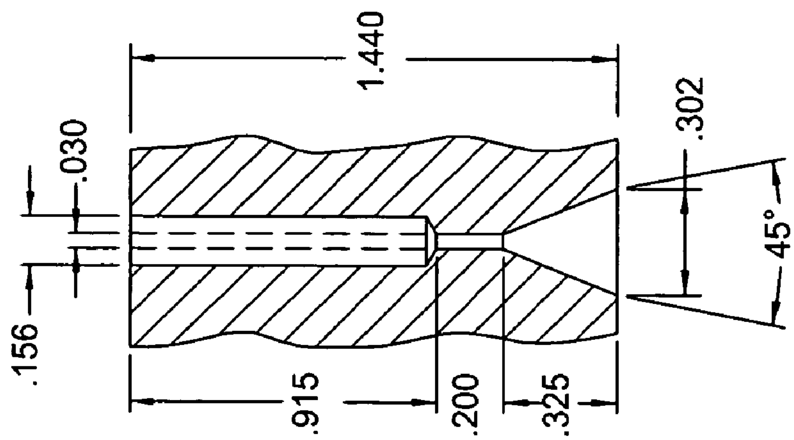


FIG. 7D

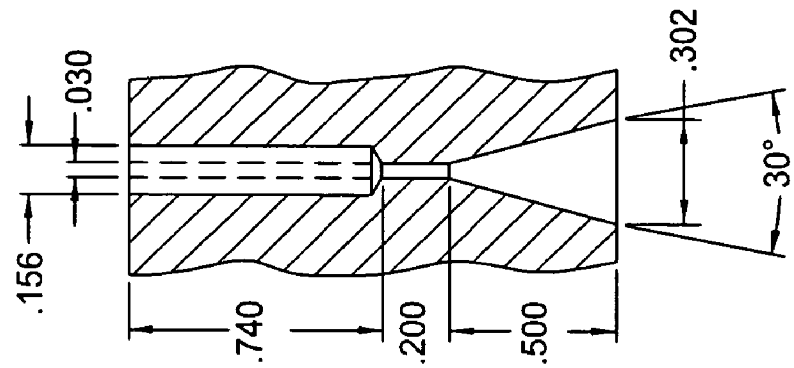


FIG. 7C

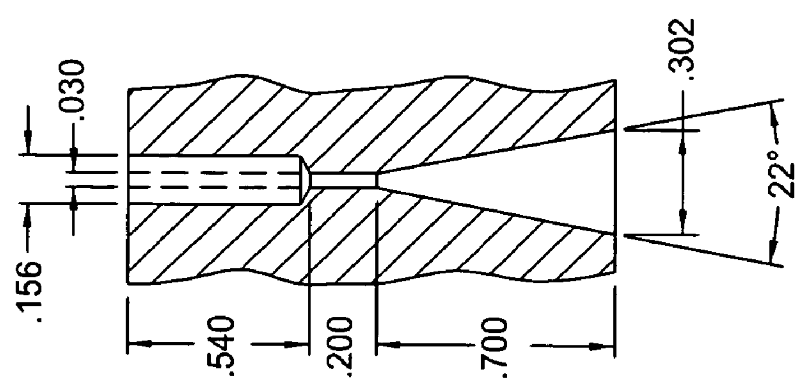
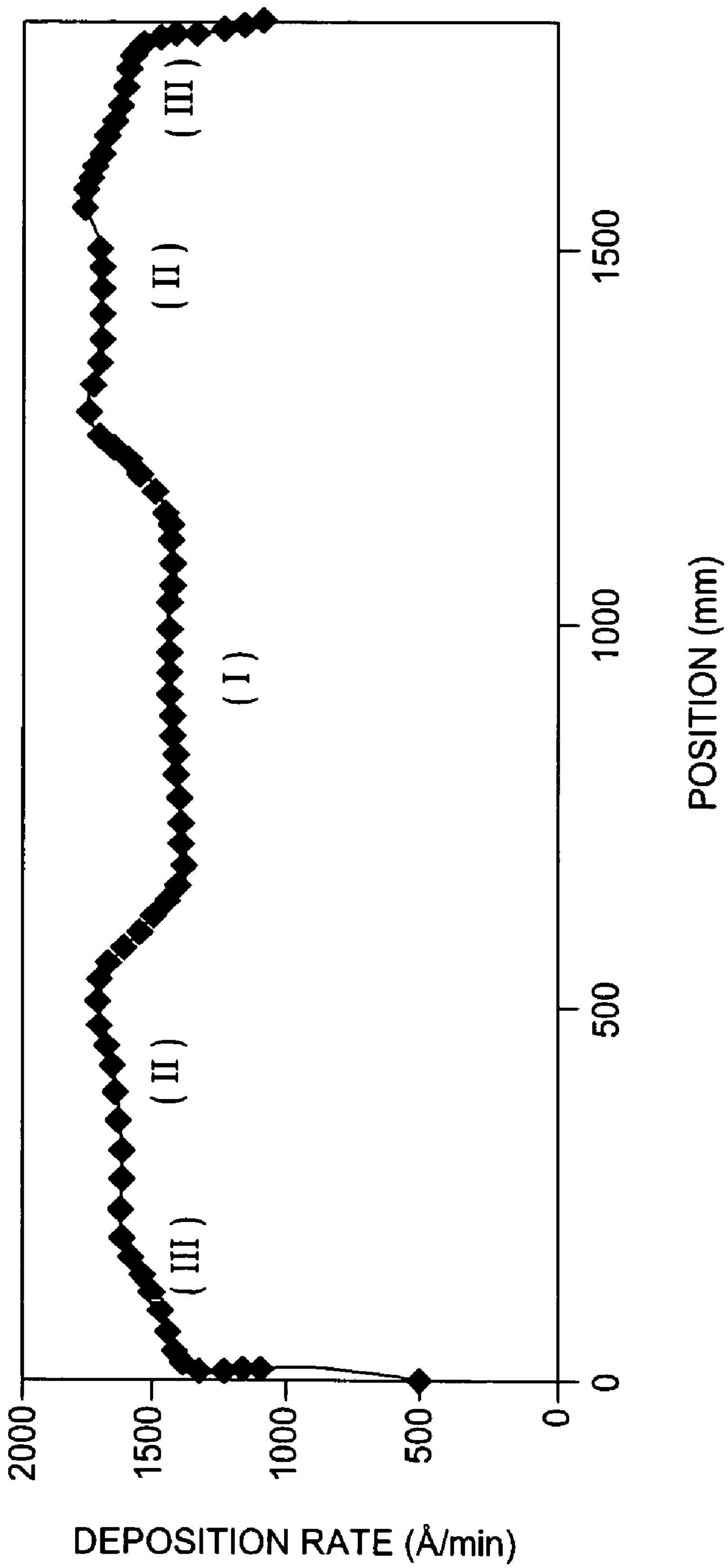


FIG. 7B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2000
1500
1000
500
0
POSITION (mm)
0
500
1000
1500
(I)
(II)
(II)
(III)
(III)

FIG. 8

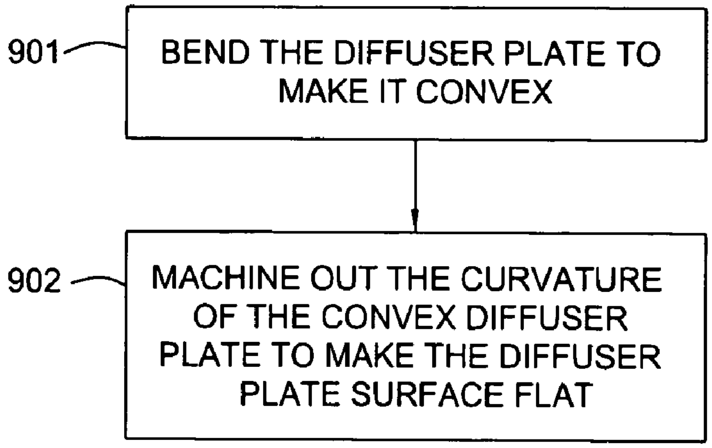


FIG. 9A

FIG. 9B

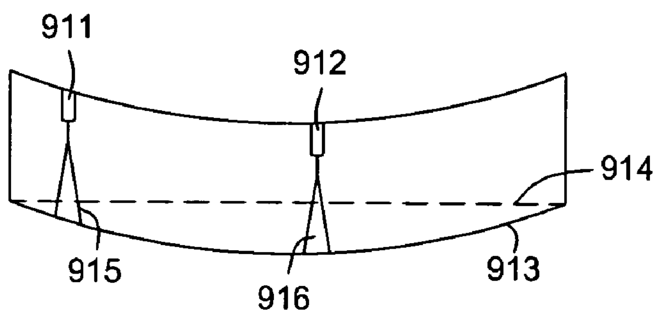
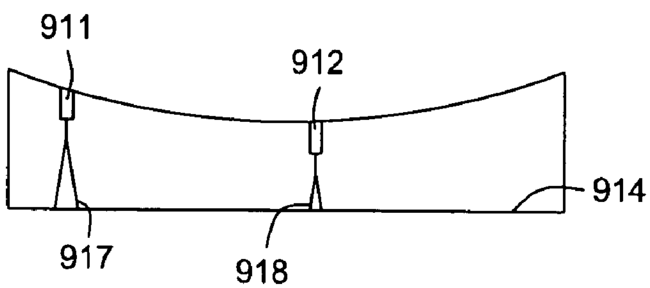


FIG. 9C



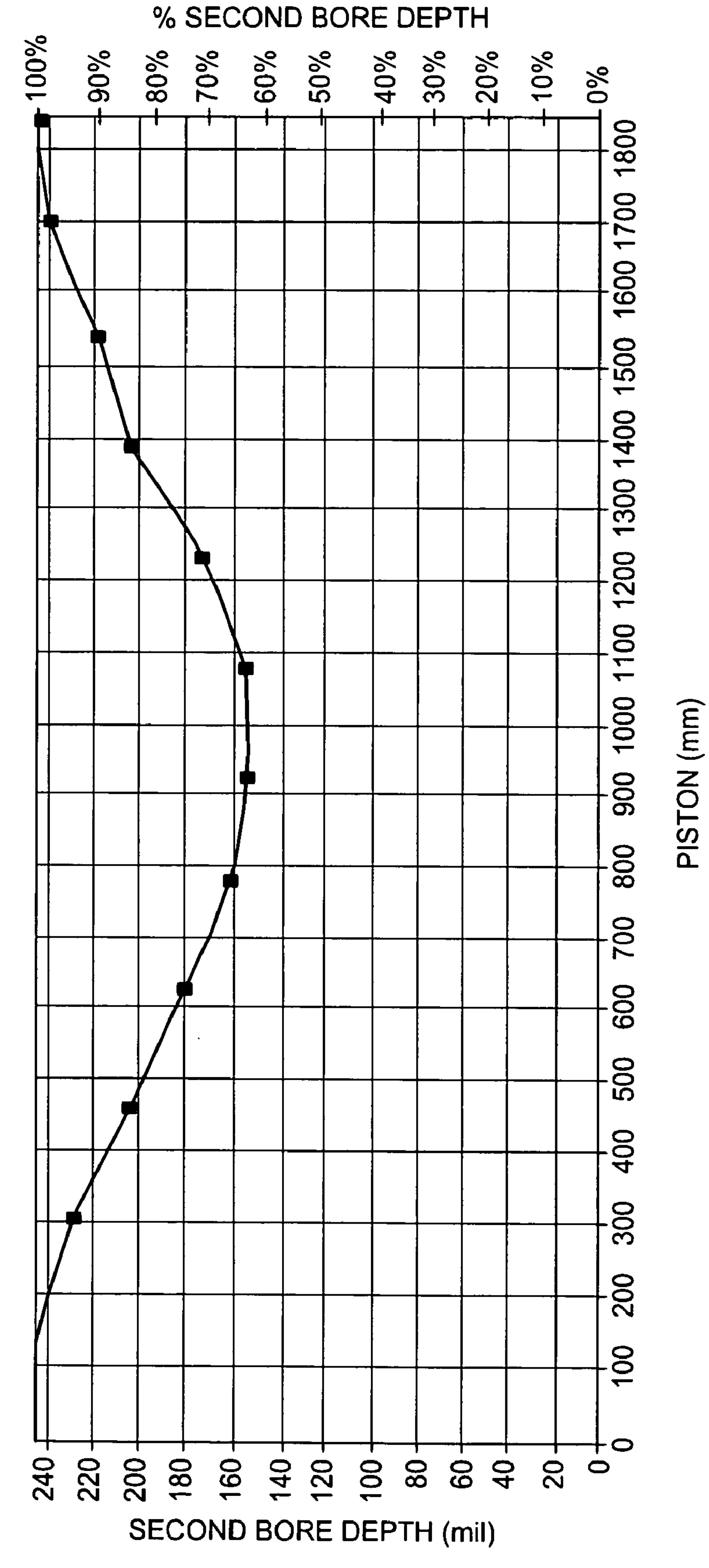
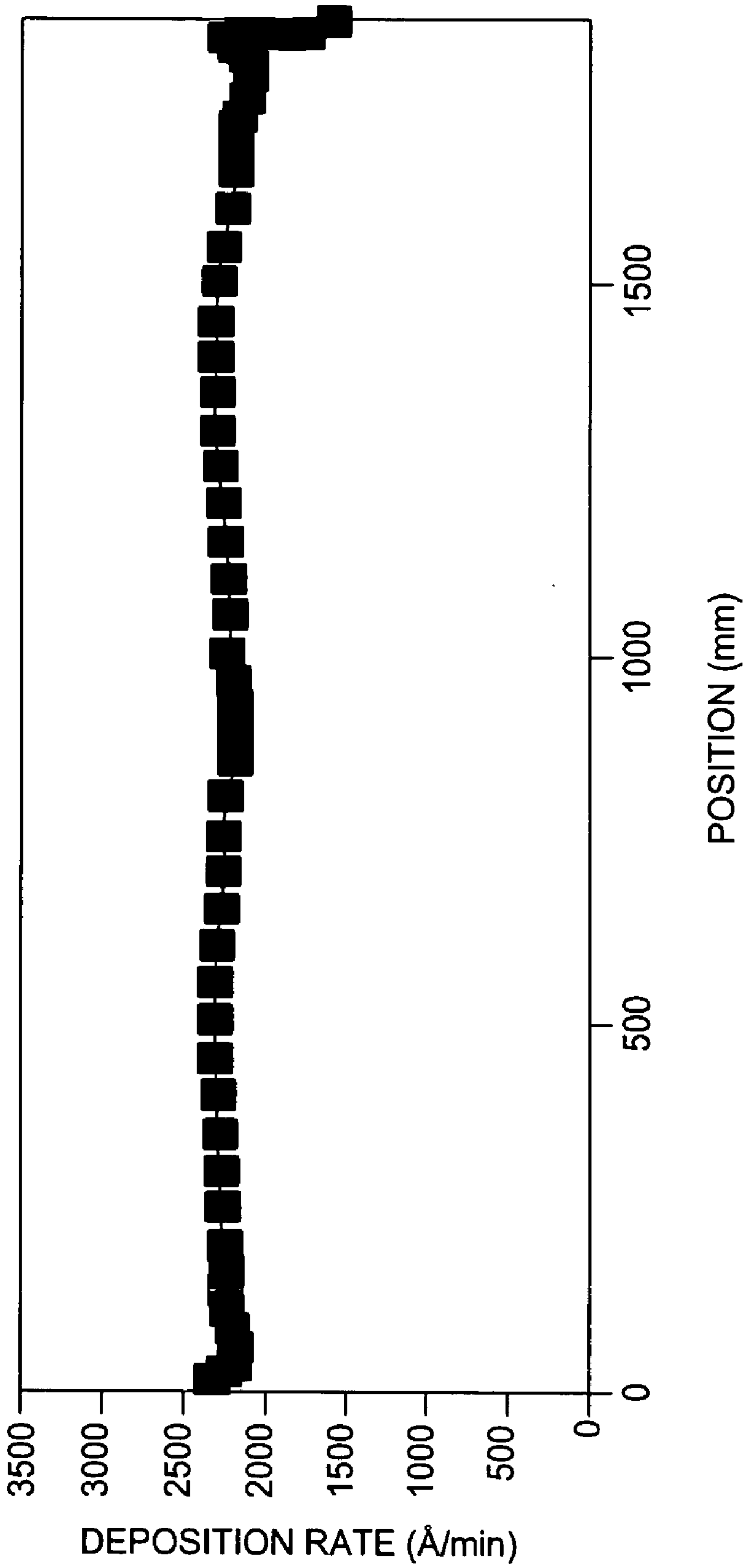

% SECOND BORE DEPTH
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
PISTON (mm)
240
220
200
180
160
140
120
100
80
60
40
20
0
SECOND BORE DEPTH (mil)

FIG. 9D


DEPOSITION RATE (Å/min)
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500
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POSITION (mm)
0
500
1000
1500

FIG. 9E

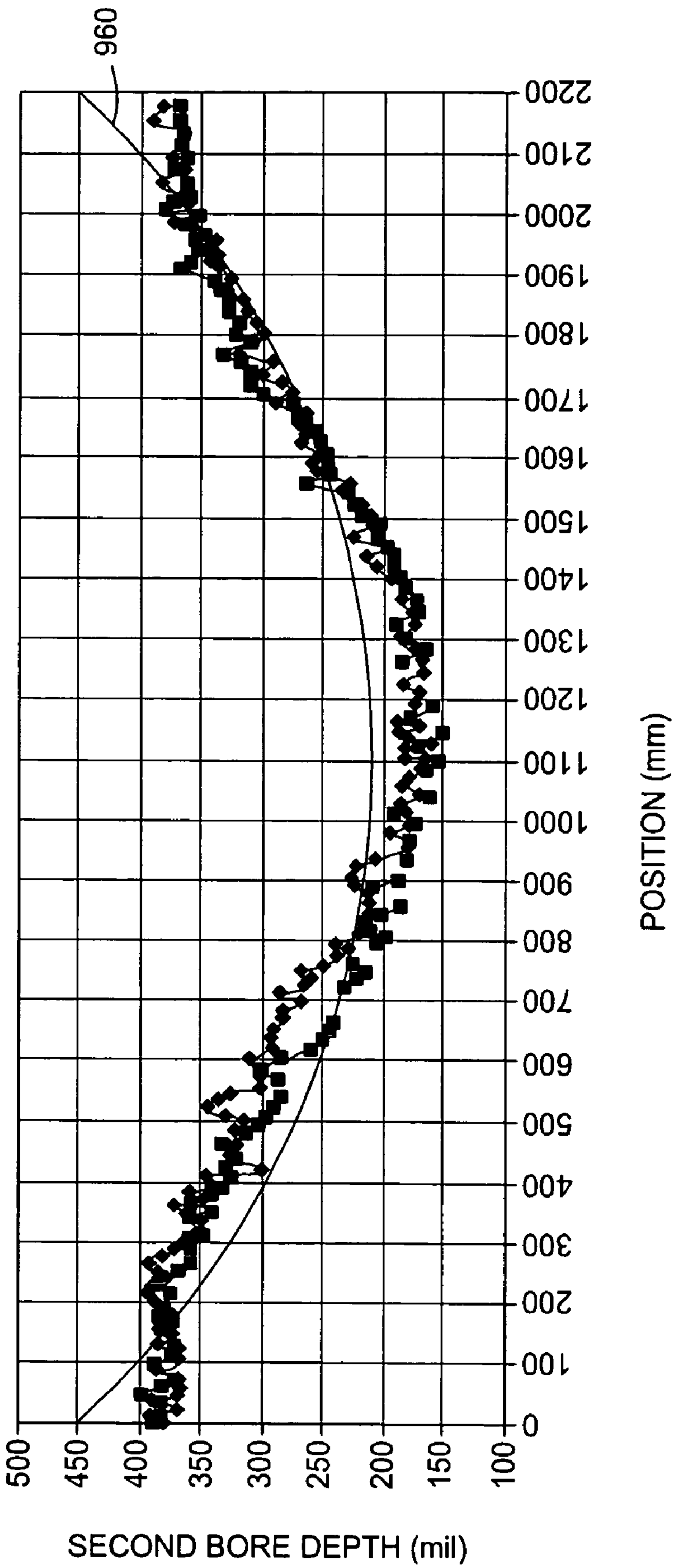

960
SECOND BORE DEPTH (mil)
500
450
400
350
300
250
200
150
100
POSITION (mm)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200

FIG. 9F

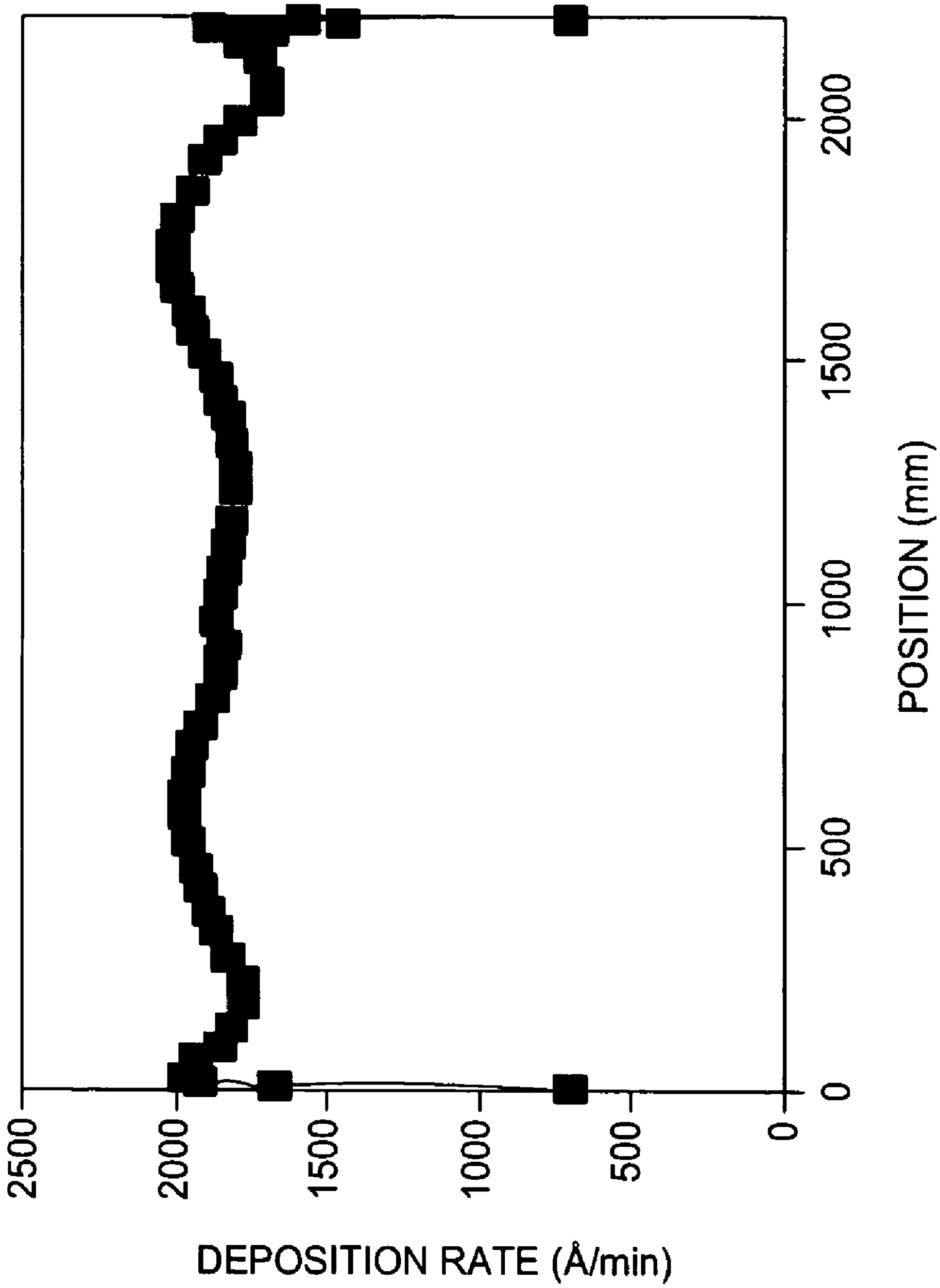

DEPOSITION RATE (Å/min)
0
500
1000
1500
2000
2500
POSITION (mm)
0
500
1000
1500
2000

FIG. 9G

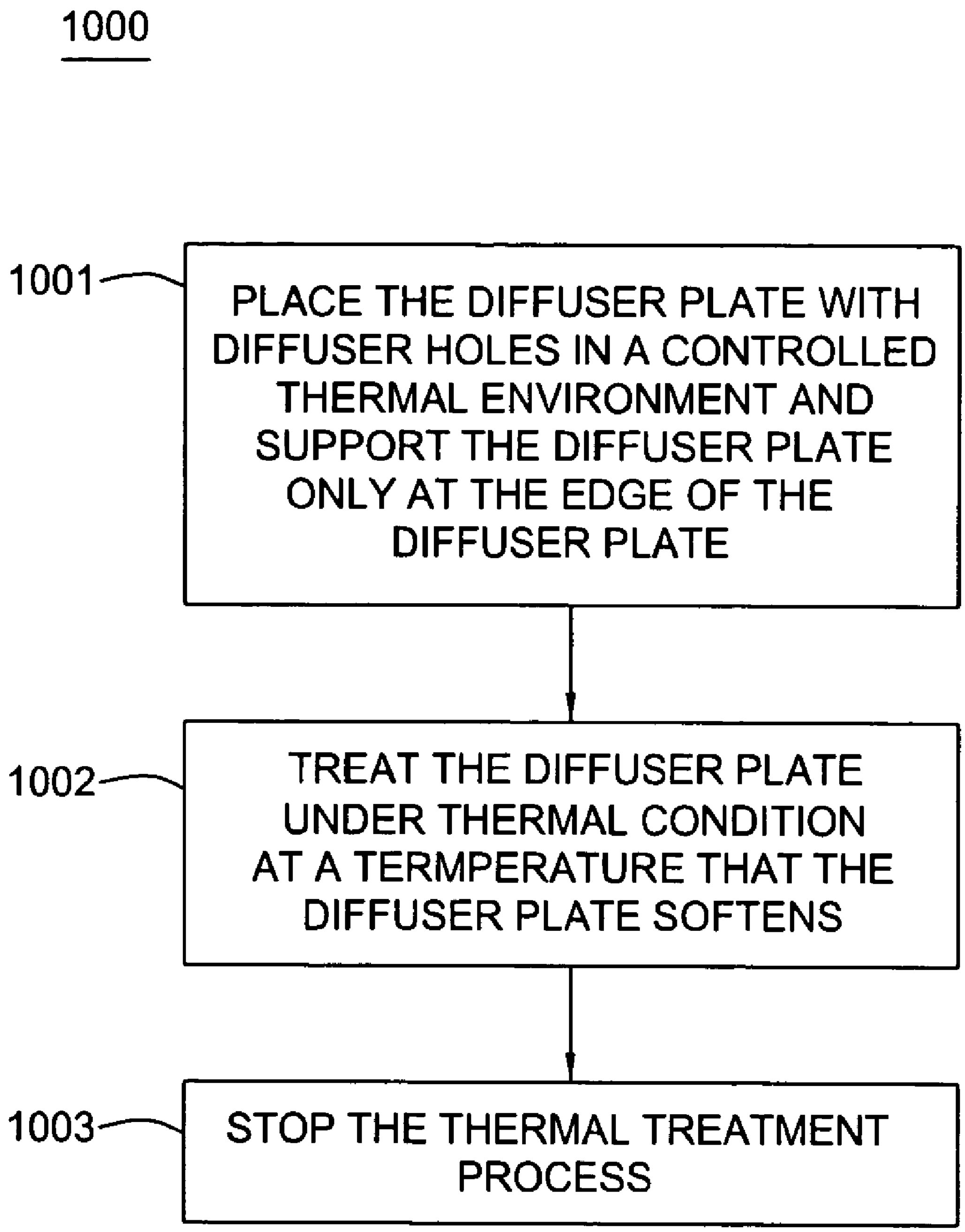

1000
1001
PLACE THE DIFFUSER PLATE WITH DIFFUSER HOLES IN A CONTROLLED THERMAL ENVIRONMENT AND SUPPORT THE DIFFUSER PLATE ONLY AT THE EDGE OF THE DIFFUSER PLATE
1002
TREAT THE DIFFUSER PLATE UNDER THERMAL CONDITION AT A TERMPERATURE THAT THE DIFFUSER PLATE SOFTENS
1003
STOP THE THERMAL TREATMENT PROCESS

FIG. 10A

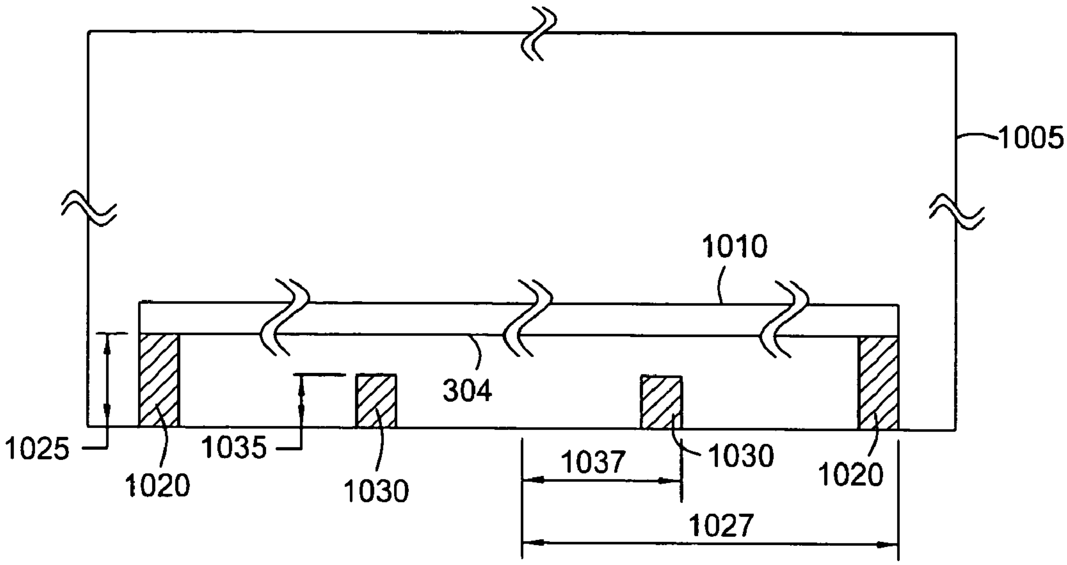


FIG. 10B

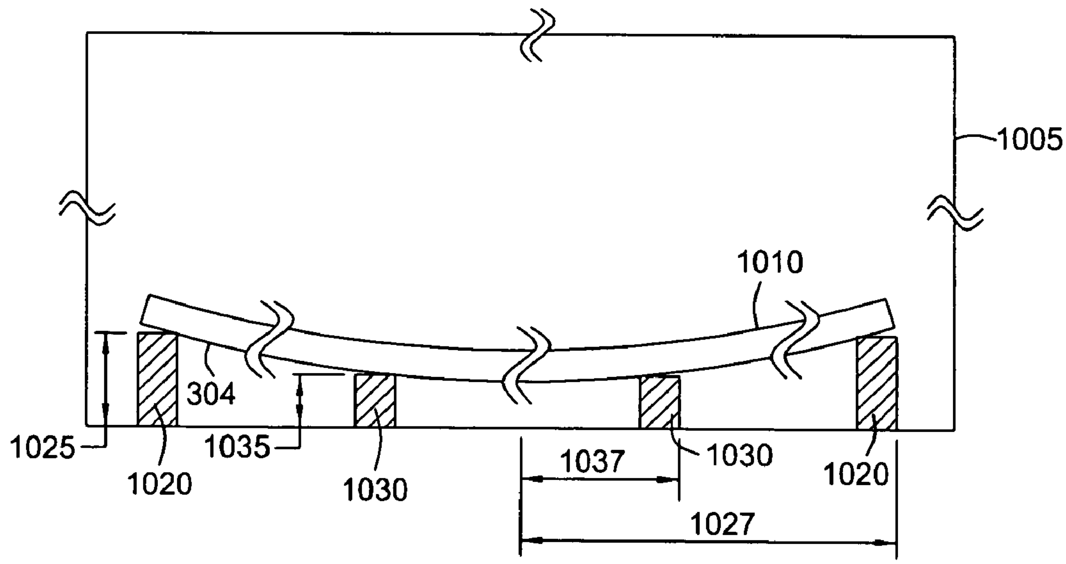


FIG. 10C

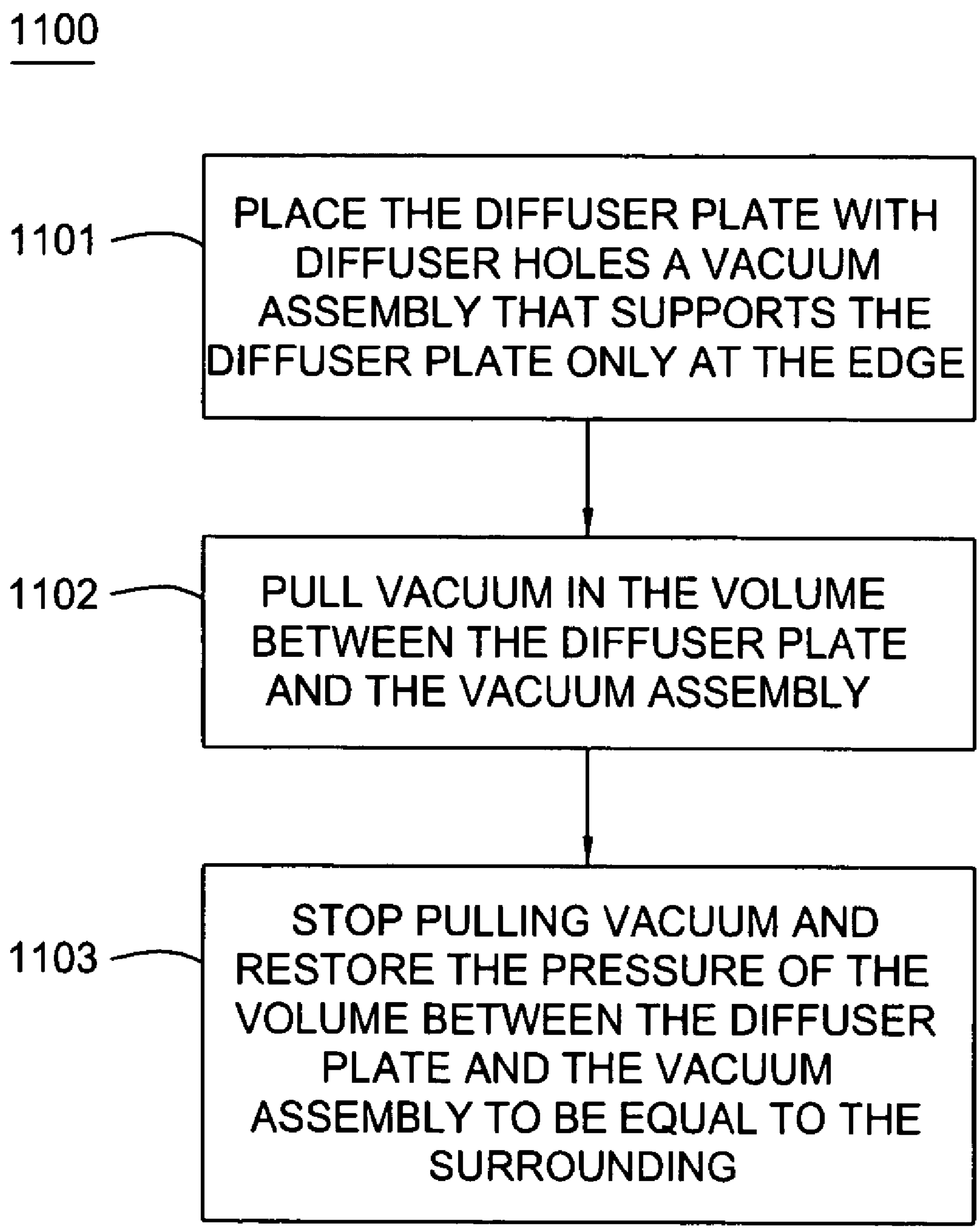

1100
1101
PLACE THE DIFFUSER PLATE WITH DIFFUSER HOLES A VACUUM ASSEMBLY THAT SUPPORTS THE DIFFUSER PLATE ONLY AT THE EDGE
1102
PULL VACUUM IN THE VOLUME BETWEEN THE DIFFUSER PLATE AND THE VACUUM ASSEMBLY
1103
STOP PULLING VACUUM AND RESTORE THE PRESSURE OF THE VOLUME BETWEEN THE DIFFUSER PLATE AND THE VACUUM ASSEMBLY TO BE EQUAL TO THE SURROUNDING

FIG. 11A

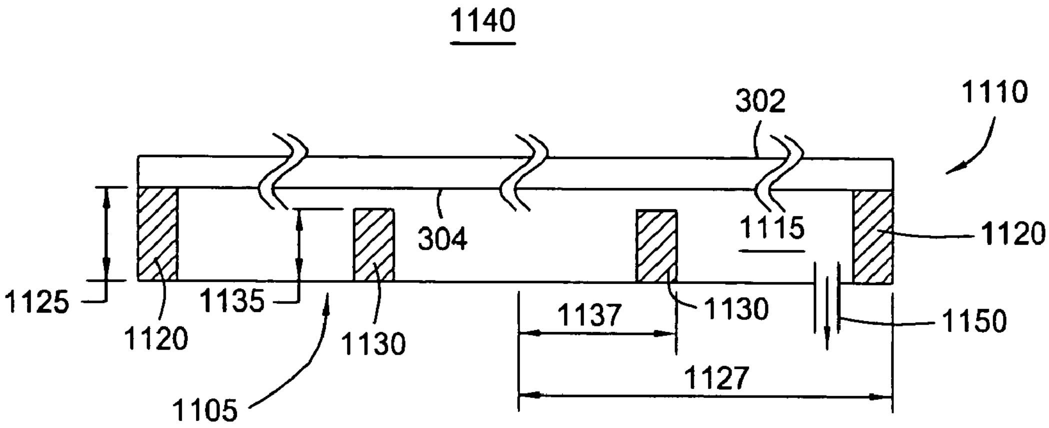


FIG. 11B

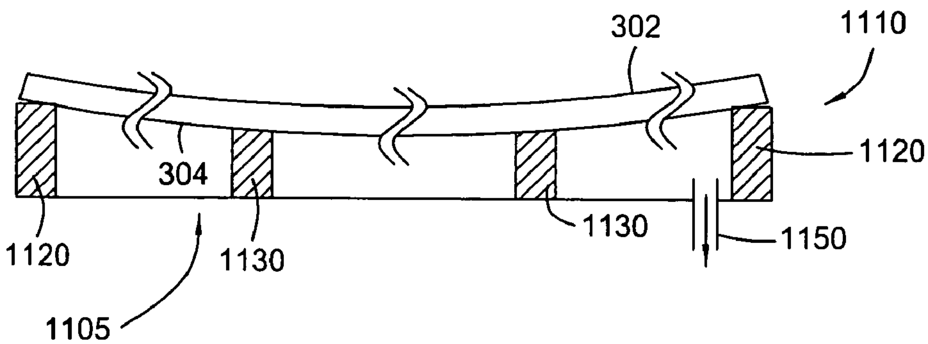


FIG. 11C

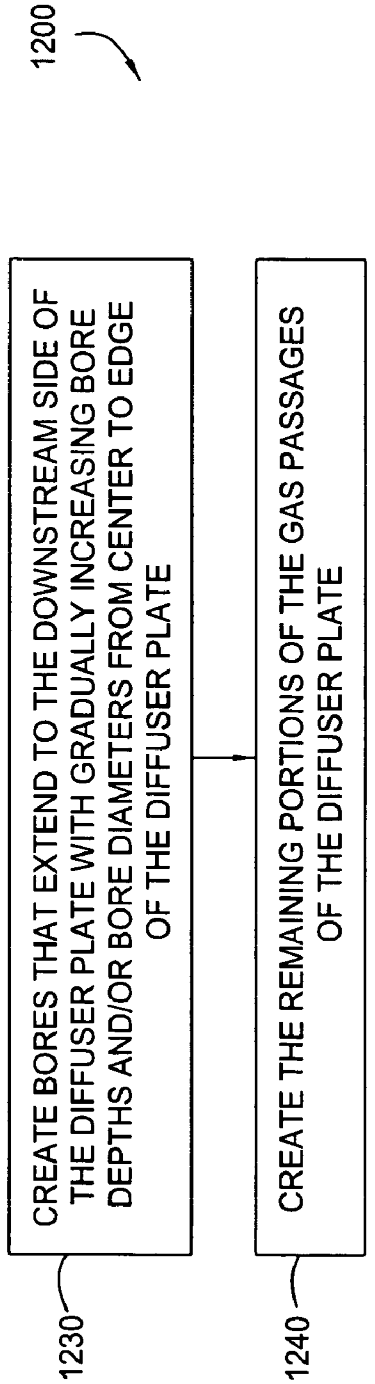


FIG. 12A

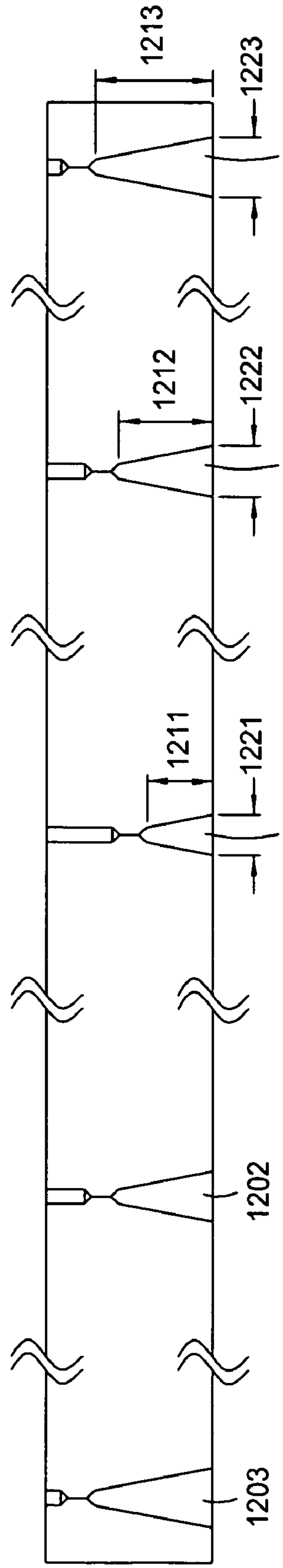


FIG. 12B

FIG. 12C

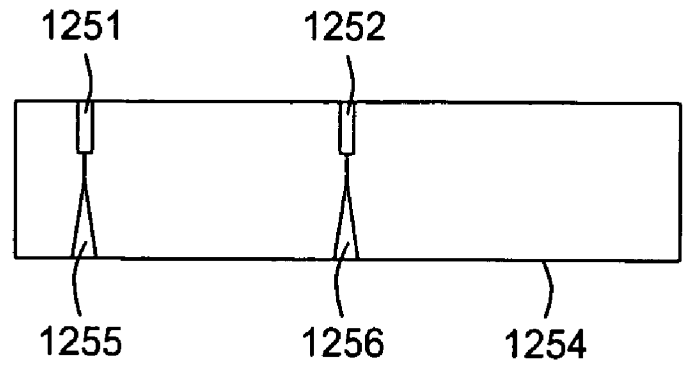


FIG. 12D

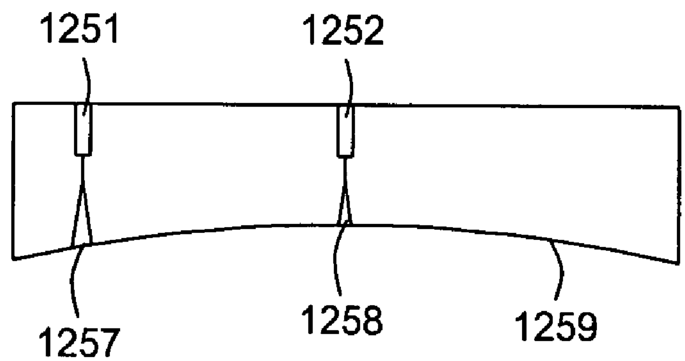


FIG. 12E

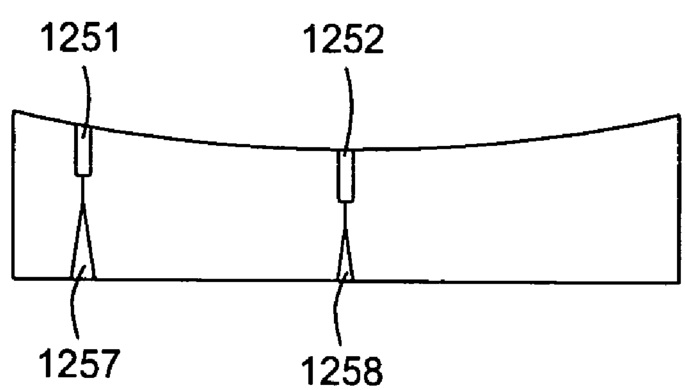


FIG. 12F

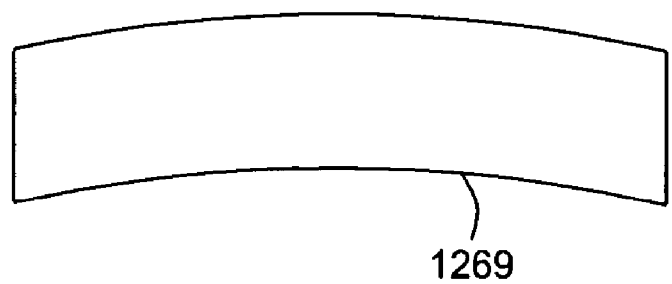


FIG. 12G

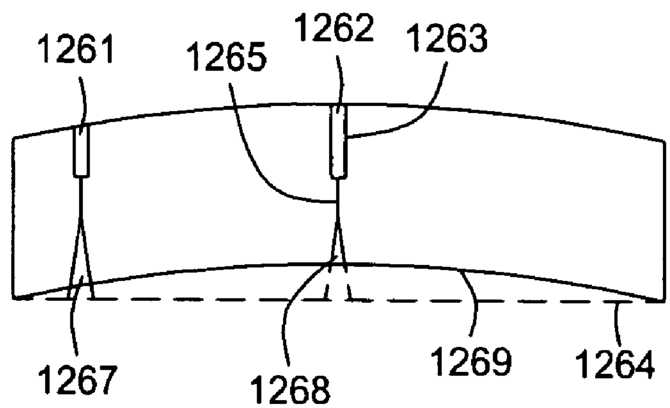
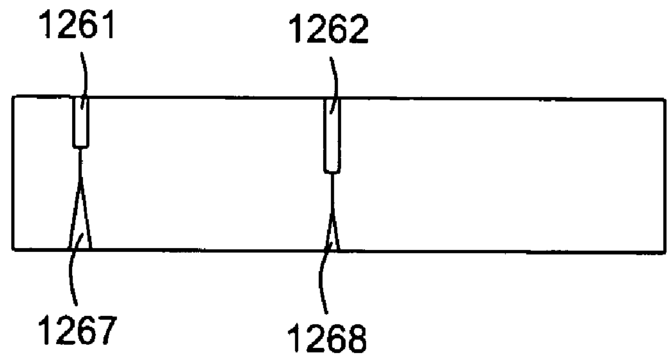


FIG. 12H



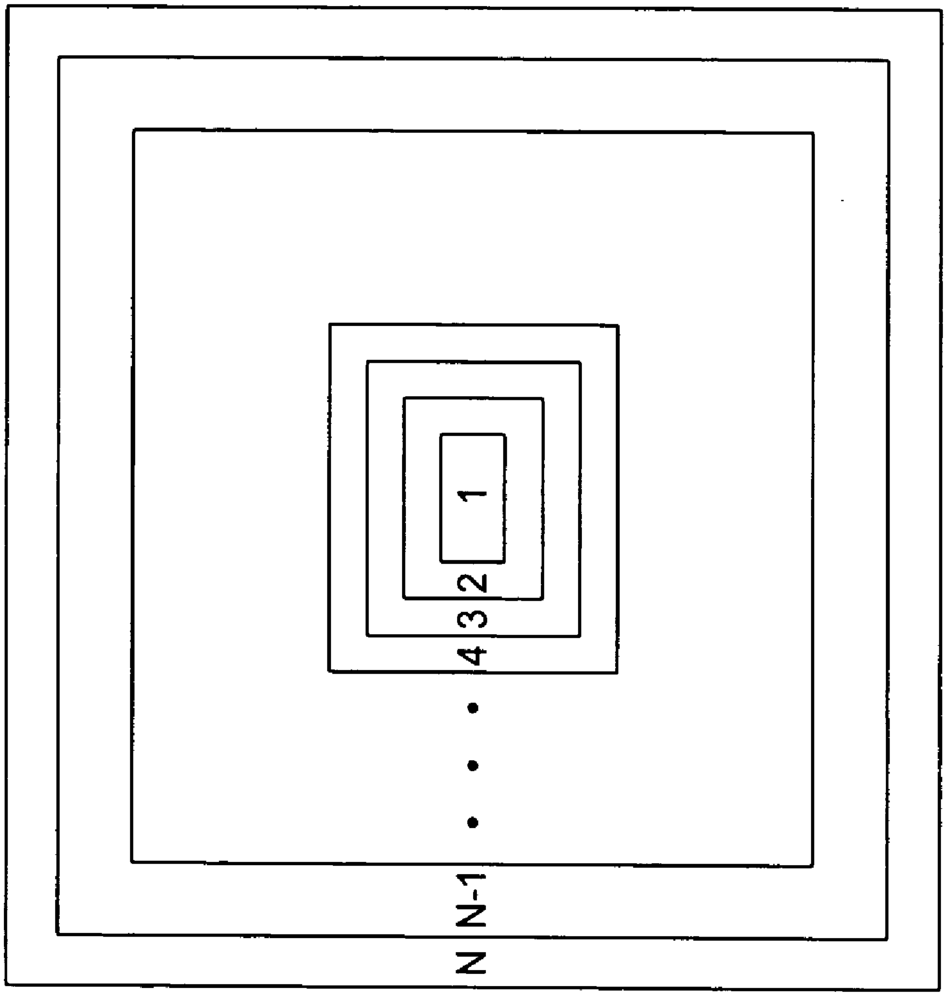


FIG. 12I

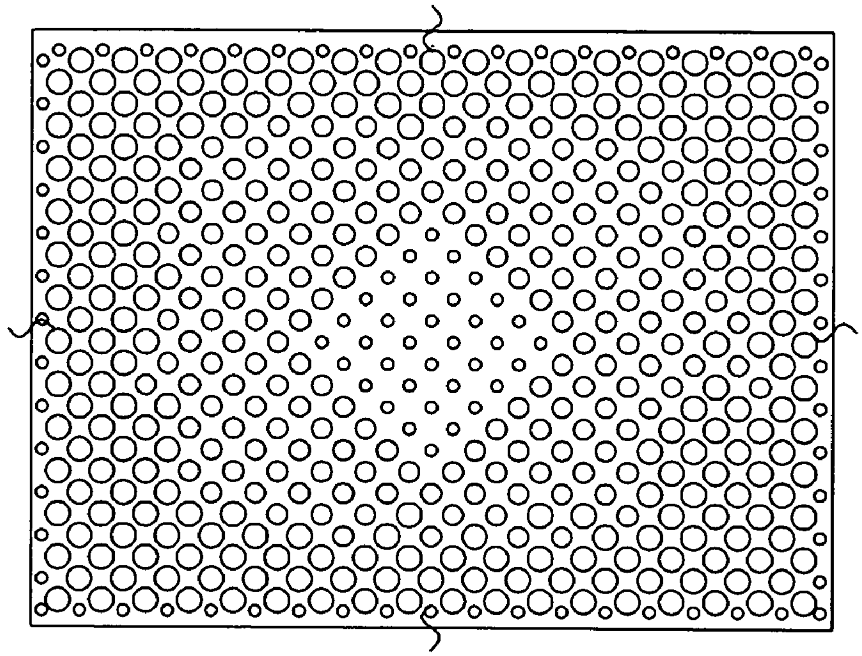


FIG. 12J

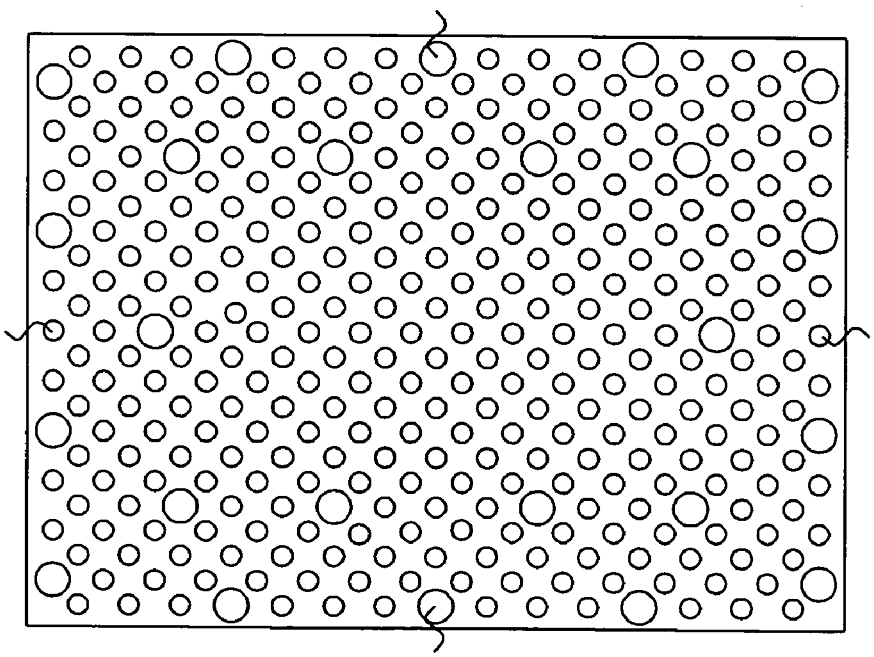


FIG. 12K

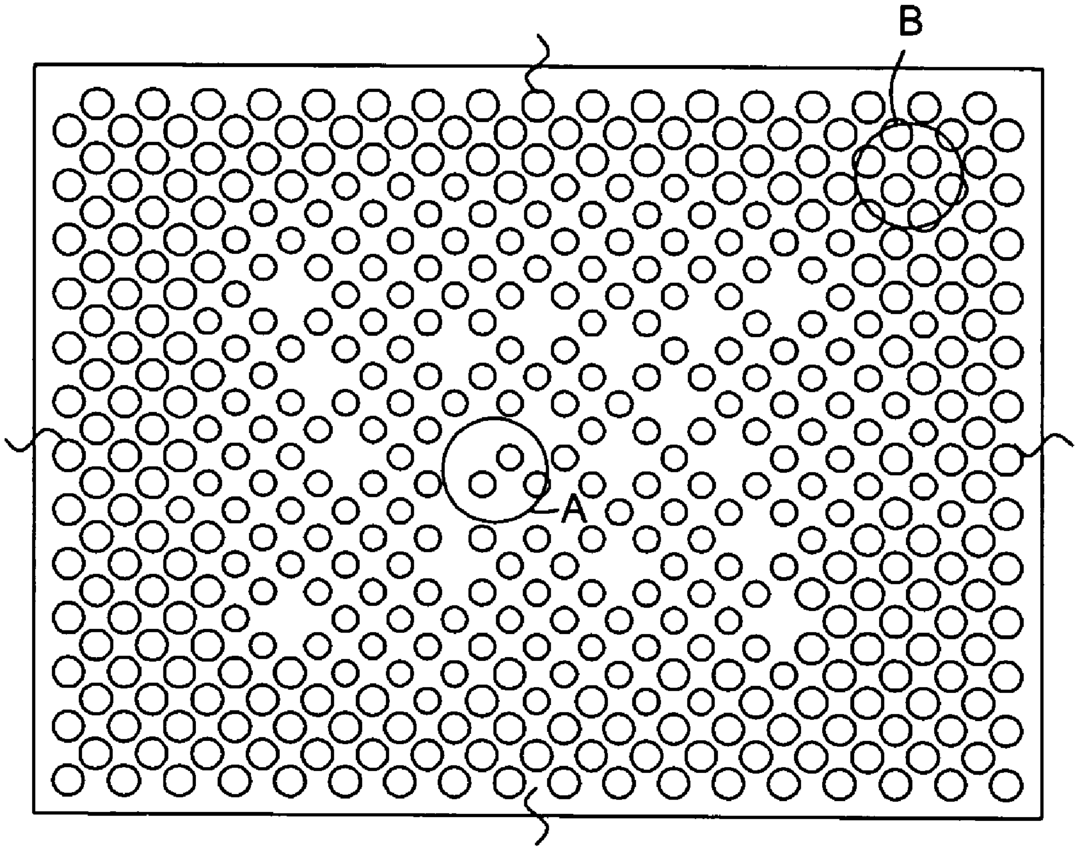


FIG. 13

PLASMA UNIFORMITY CONTROL BY GAS DIFFUSER HOLE DESIGN

CROSS-REFERENCE TO OTHER APPLICATIONS

[0001] This application is a continuation of co-pending U.S. patent application Ser. No. 10/889,683, filed Jul. 12, 2004, which claims benefit of U.S. provisional patent application Ser. No. 60/570,876, filed May 5, 2004. Each of the aforementioned related patent applications is herein incorporated by reference.

BACKGROUND OF THE DISCLOSURE

[0002] 1. Field of the Invention

[0003] Embodiments of the invention generally relate to a gas distribution plate assembly and method for distributing gas in a processing chamber.

[0004] 2. Description of the Background Art

[0005] Liquid crystal displays or flat panels are commonly used for active matrix displays such as computer and television monitors. Plasma enhanced chemical vapor deposition (PECVD) is generally employed to deposit thin films on a substrate such as a transparent substrate for flat panel display or semiconductor wafer. PECVD is generally accomplished by introducing a precursor gas or gas mixture into a vacuum chamber that contains a substrate. The precursor gas or gas mixture is typically directed downwardly through a distribution plate situated near the top of the chamber. The precursor gas or gas mixture in the chamber is energized (e.g., excited) into a plasma by applying radio frequency (RF) power to the chamber from one or more RF sources coupled to the chamber. The excited gas or gas mixture reacts to form a layer of material on a surface of the substrate that is positioned on a temperature controlled substrate support. Volatile by-products produced during the reaction are pumped from the chamber through an exhaust system.

[0006] Flat panels processed by PECVD techniques are typically large, often exceeding 370 mm×470 mm. Large area substrates approaching and exceeding 4 square meters are envisioned in the near future. Gas distribution plates (or gas diffuser plates) utilized to provide uniform process gas flow over flat panels are relatively large in size, particularly as compared to gas distribution plates utilized for 200 mm and 300 mm semiconductor wafer processing.

[0007] As the size of substrates continues to grow in the TFT-LCD industry, film thickness and film property uniformity control for large area plasma-enhanced chemical vapor deposition (PECVD) becomes an issue. TFT is one type of flat panel display. The difference of deposition rate and/or film property, such as film stress, between the center and the edge of the substrate becomes significant.

[0008] Therefore, there is a need for an improved gas distribution plate assembly that improves the uniformities of film deposition thickness and film properties.

SUMMARY OF THE INVENTION

[0009] The present invention generally provide a gas distribution plate assembly for a plasma processing chamber, comprising a diffuser plate having an upstream side and a downstream side, and an array of gas passages passing between the upstream and downstream sides of the diffuser plate, wherein the array of gas passages comprise a first gas passage having a first hollow cathode cavity that is proximate to the downstream side and has a first surface area and a second gas passage that is positioned closer to a center point of the diffuser plate than the first gas passage and has a second hollow cathode cavity that is proximate to the downstream side and has a second surface area, wherein the first surface area is less than the second surface area.

[0010] Embodiments of the invention further provide a gas distribution plate assembly for a plasma processing chamber, comprising a diffuser plate having an upstream side and a downstream side, and an array of gas passages passing between the upstream and downstream sides of the diffuser plate, wherein the array of gas passages comprise a plurality of first gas passages having a first hollow cathode cavity that each have a first diameter that is in contact with the downstream side and a first depth, and a plurality of second gas passages that are positioned closer to a center point of the diffuser plate than the plurality of first gas passages and each of the plurality of second gas passages have a second hollow cathode cavity that has a second diameter that is in contact with the downstream side and a second depth, wherein the second diameter is larger than the first diameter or the second depth is larger than the first depth.

[0011] Embodiments of the invention further provide a gas distribution plate assembly for a plasma processing chamber, comprising a diffuser plate having an upstream side and a downstream side, and an array of gas passages passing between the upstream and downstream sides of the diffuser plate, wherein the array of gas passages comprise a plurality of first gas passages having a first hollow cathode cavity that each have a first diameter that is in contact with the downstream side, a first flaring angle, and a first depth, and a plurality of second gas passages that have a second hollow cathode cavity that has a second diameter that is in contact with the downstream side, a second flaring angle and a second depth, wherein the second diameter is greater than the first diameter, the second flaring angle is greater than the first flaring angle, or the second depth is greater than the first depth.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

[0013] **FIG. 1** depicts a cross-sectional schematic view of a bottom gate thin film transistor.

[0014] **FIG. 2** is a schematic cross-sectional view of an illustrative processing chamber having one embodiment of a gas distribution plate assembly of the present invention.

[0015] **FIG. 3** depicts a cross-sectional schematic view of a gas diffuser plate.

[0016] **FIG. 4A** shows the process flow of depositing a thin film on a substrate in a process chamber with a diffuser plate.

[0017] **FIG. 4B** shows the deposition rate measurement across a 1500 mm by 1800 mm substrate collected from deposition with a diffuser plate with uniform diffuser holes diameters and depths.

[0018] **FIG. 5** shows 2 sides (**501** and **502**) of the substrate that are close to the sides with pumping plenum closed and the 5 measurement locations on a substrate.

[0019] **FIG. 6A** (Prior Art) illustrates the concept of hollow cathode effect.

[0020] **FIGS. 6B-6G** illustrates various designs of hollow cathode cavities.

[0021] **FIG. 7A** shows the definition of diameter "D", the depth "d" and the flaring angle "α" of the bore that extends to the downstream end of a gas passage.

[0022] **FIG. 7B** shows the dimensions of a gas passage.

[0023] **FIG. 7C** shows the dimensions of a gas passage.

[0024] **FIG. 7D** shows the dimensions of a gas passage.

[0025] **FIG. 7E** shows the distribution of gas passages across a diffuser plate.

[0026] **FIG. 8** shows the deposition rate measurement across a 1500 mm by 1800 mm substrate collected from deposition with a diffuser plate with a distribution of gas passages across the diffuser plate as shown in **FIG. 7E**.

[0027] **FIG. 9A** shows the process flow of making a diffuser plate.

[0028] **FIG. 9B** shows a bent diffuser plate.

[0029] **FIG. 9C** shows a diffuser plate that was previously bent and the side that facing the downstream side was machined to be flat.

[0030] **FIG. 9D** shows the distribution of depths of diffuser bores that extends to the downstream ends of gas passages of a diffuser plate used to process 1500 mm by 1850 mm substrates.

[0031] **FIG. 9E** shows the measurement of deposition rates across a 1500 mm by 1850 mm substrate.

[0032] **FIG. 9F** shows the distribution of depths of diffuser bores that extends to the downstream ends of gas passages of a diffuser plate used to process 1870 mm by 2200 mm substrates.

[0033] **FIG. 9G** shows the measurement of deposition rates across an 1870 mm by 2200 mm substrate.

[0034] **FIG. 10A** shows the process flow of bending the diffuser plate by a thermal process.

[0035] **FIG. 1O**B shows the diffuser plate on the supports in the thermal environment that could be used to bend the diffuser plate.

[0036] **FIG. 10C** shows the convex diffuser plate on the supports in the thermal environment.

[0037] **FIG. 11A** shows the process flow of bending the diffuser plate by a vacuum process.

[0038] **FIG. 11B** shows the diffuser plate on the vacuum assembly.

[0039] **FIG. 11C** shows the convex diffuser plate on the vacuum assembly.

[0040] **FIG. 12A** shows the process flow of creating a diffuser plate with varying diameters and depths of bores that extends to the downstream side of the diffuser plate.

[0041] **FIG. 12B** shows the cross section of a diffuser plate with varying diameters and depths of bores that extends to the downstream side of the diffuser plate.

[0042] **FIG. 12C** shows a diffuser plate with substantially identical diffuser holes from center to edge of the diffuser plate.

[0043] **FIG. 12D** shows the diffuser plate of **FIG. 12C** after the bottom surface has been machined into a concave shape.

[0044] **FIG. 12E** shows the diffuser plate of **FIG. 12D** after its bottom surface has been pulled substantially flat.

[0045] **FIG. 12F** shows a diffuser plate, without any diffuser holes, that has been bent into a concave (bottom surface) shape.

[0046] **FIG. 12G** shows the diffuser plate of **FIG. 12F** with diffuser holes.

[0047] **FIG. 12H** shows the diffuser plate of **FIG. 12G** after its bottom surface has been pulled substantially flat.

[0048] **FIG. 12I** shows a diffuser plate with diffuser holes in multiple zones.

[0049] **FIG. 12J** shows a diffuser plate with mixed hollow cathode cavity diameters and the inner region hollow cathode cavity volume and/or surface area density is higher than the outer region hollow cathode cavity volume and/or surface area density.

[0050] **FIG. 12K** shows a diffuser plate with most of the hollow cathode cavities the same, while there are a few larger hollow cathode cavities near the edge of the diffuser plate.

[0051] **FIG. 13** shows the downstream side view of a diffuser plate with varying diffuser hole densities.

[0052] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION

[0053] The invention generally provides a gas distribution assembly for providing gas delivery within a processing chamber. The invention is illustratively described below in reference to a plasma enhanced chemical vapor deposition system configured to process large area substrates, such as a plasma enhanced chemical vapor deposition (PECVD) system, available from AKT, a division of Applied Materials, Inc., Santa Clara, Calif. However, it should be understood that the invention has utility in other system configurations such as etch systems, other chemical vapor deposition systems and any other system in which distributing gas within a process chamber is desired, including those systems configured to process round substrates.

[0054] **FIG. 1** illustrates cross-sectional schematic views of a thin film transistor structure. A common TFT structure is the back channel etch (BCE) inverted staggered (or bottom gate) TFT structure shown in **FIG. 1**. The BCE process is preferred, because the gate dielectric (SiN), and the intrinsic as well as n+ doped amorphous silicon films can be deposited in the same PECVD pump-down run. The BCE process shown here involves only 5 patterning masks. The substrate **101** may comprise a material that is essentially optically transparent in the visible spectrum, such as, for example, glass or clear plastic. The substrate may be of varying shapes or dimensions. Typically, for TFT applications, the substrate is a glass substrate with a surface area greater than about 500 mm^2. A gate electrode layer **102** is formed on the substrate **101**. The gate electrode layer **102** comprises an electrically conductive layer that controls the movement of charge carriers within the TFT. The gate electrode layer **102** may comprise a metal such as, for example, aluminum (Al), tungsten (W), chromium (Cr), tantalum (Ta), or combinations thereof, among others. The gate electrode layer **102** may be formed using conventional deposition, lithography and etching techniques. Between the substrate **101** and the gate electrode layer **102**, there may be an optional insulating material, for example, such as silicon dioxide (SiO_2) or silicon nitride (SiN), which may also be formed using an embodiment of a PECVD system described in this invention. The gate electrode layer **102** is then lithographically patterned and etched using conventional techniques to define the gate electrode.

[0055] A gate dielectric layer **103** is formed on the gate electrode layer **102**. The gate dielectric layer **103** may be silicon dioxide (SiO_2), silicon oxynitride (SiON), or silicon nitride (SiN), deposited using an embodiment of a PECVD system described in this invention. The gate dielectric layer **103** may be formed to a thickness in the range of about 100 Å to about 6000 Å.

[0056] A bulk semiconductor layer **104** is formed on the gate dielectric layer **103**. The bulk semiconductor layer **104** may comprise polycrystalline silicon (polysilicon) or amorphous silicon (α-Si), which could be deposited using an embodiment of a PECVD system described in this invention or other conventional methods known to the art. Bulk semiconductor layer **104** may be deposited to a thickness in the range of about 100 Å to about 3000 Å. A doped semiconductor layer **105** is formed on top of the bulk semiconductor layer **104**. The doped semiconductor layer **105** may comprise n-type (n+) or p-type (p+) doped polycrystalline (polysilicon) or amorphous silicon (α-Si), which could be deposited using an embodiment of a PECVD system described in this invention or other conventional methods known to the art. Doped semiconductor layer **105** may be deposited to a thickness within a range of about 100 Å to about 3000 Å. An example of the doped semiconductor layer **105** is n+ doped α-Si film. The bulk semiconductor layer **104** and the doped semiconductor layer **105** are lithographically patterned and etched using conventional techniques to define a mesa of these two films over the gate dielectric insulator, which also serves as storage capacitor dielectric. The doped semiconductor layer **105** directly contacts portions of the bulk semiconductor layer **104**, forming a semiconductor junction.

[0057] A conductive layer **106** is then deposited on the exposed surface. The conductive layer **106** may comprise a metal such as, for example, aluminum (Al), tungsten (W), molybdenum (Mo), chromium (Cr), tantalum (Ta), and combinations thereof, among others. The conductive layer **106** may be formed using conventional deposition techniques. Both the conductive layer **106** and the doped semiconductor layer **105** may be lithographically patterned to define source and drain contacts of the TFT. Afterwards, a passivation layer **107** may be deposited. Passivation layer **107** conformably coats exposed surfaces. The passivation layer **107** is generally an insulator and may comprise, for example, silicon dioxide (SiO_2) or silicon nitride (SiN). The passivation layer **107** may be formed using, for example, PECVD or other conventional methods known to the art. The passivation layer **107** may be deposited to a thickness in the range of about 1000 Å to about 5000 Å. The passivation layer **107** is then lithographically patterned and etched using conventional techniques to open contact holes in the passivation layer.

[0058] A transparent conductor layer **108** is then deposited and patterned to make contacts with the conductive layer **106**. The transparent conductor layer **108** comprises a material that is essentially optically transparent in the visible spectrum and is electrically conductive. Transparent conductor layer **108** may comprise, for example, indium tin oxide (ITO) or zinc oxide, among others. Patterning of the transparent conductive layer **108** is accomplished by conventional lithographical and etching techniques.

[0059] The doped or un-doped (intrinsic) amorphous silicon (α-Si), silicon dioxide (SiO2), silicon oxynitride (SiON) and silicon nitride (SiN) films used in liquid crystal displays (or flat panels) could all be deposited using an embodiment of a plasma enhanced chemical vapor deposition (PECVD) system described in this invention. The TFT structure described here is merely used as an example. The current invention applies to manufacturing any devices that are applicable.

[0060] **FIG. 2** is a schematic cross-sectional view of one embodiment of a plasma enhanced chemical vapor deposition system **200**, available from AKT, a division of Applied Materials, Inc., Santa Clara, Calif. The system **200** generally includes a processing chamber **202** coupled to a gas source **204**. The processing chamber **202** has walls **206** and a bottom **208** that partially define a process volume **212**. The process volume **212** is typically accessed through a port (not shown) in the walls **206** that facilitate movement of a substrate **240** into and out of the processing chamber **202**. The walls **206** and bottom **208** are typically fabricated from a unitary block of aluminum or other material compatible with processing. The walls **206** support a lid assembly **210** that contains a pumping plenum **214** that couples the process volume **212** to an exhaust port (that includes various pumping components, not shown).

[0061] A temperature controlled substrate support assembly **238** is centrally disposed within the processing chamber **202**. The support assembly **238** supports a glass substrate **240** during processing. In one embodiment, the substrate support assembly **238** comprises an aluminum body **224** that encapsulates at least one embedded heater **232**. The heater **232**, such as a resistive element, disposed in the support assembly **238**, is coupled to an optional power source **274** and controllably heats the support assembly **238** and the glass substrate **240** positioned thereon to a predetermined temperature. Typically, in a CVD process, the heater **232** maintains the glass substrate **240** at a uniform temperature between about 150 to at least about 460 degrees Celsius, depending on the deposition processing parameters for the material being deposited.

[0062] Generally, the support assembly **238** has a lower side **226** and an upper side **234**. The upper side **234** supports the glass substrate **240**. The lower side **226** has a stem **242** coupled thereto. The stem **242** couples the support assembly

238 to a lift system (not shown) that moves the support assembly **238** between an elevated processing position (as shown) and a lowered position that facilitates substrate transfer to and from the processing chamber **202**. The stem **242** additionally provides a conduit for electrical and thermocouple leads between the support assembly **238** and other components of the system **200**.

[0063] A bellows **246** is coupled between support assembly **238** (or the stem **242**) and the bottom **208** of the processing chamber **202**. The bellows **246** provides a vacuum seal between the process volume **212** and the atmosphere outside the processing chamber **202** while facilitating vertical movement of the support assembly **238**.

[0064] The support assembly **238** generally is grounded such that RF power supplied by a power source **222** to a gas distribution plate assembly **218** positioned between the lid assembly **210** and substrate support assembly **238** (or other electrode positioned within or near the lid assembly of the chamber) may excite gases present in the process volume **212** between the support assembly **238** and the distribution plate assembly **218**. The RF power from the power source **222** is generally selected commensurate with the size of the substrate to drive the chemical vapor deposition process.

[0065] The support assembly **238** additionally supports a circumscribing shadow frame **248**. Generally, the shadow frame **248** prevents deposition at the edge of the glass substrate **240** and support assembly **238** so that the substrate does not stick to the support assembly **238**. The support assembly **238** has a plurality of holes **228** disposed therethrough that accept a plurality of lift pins **250**. The lift pins **250** are typically comprised of ceramic or anodized aluminum. The lift pins **250** may be actuated relative to the support assembly **238** by an optional lift plate **254** to project from the support surface **230**, thereby placing the substrate in a spaced-apart relation to the support assembly **238**.

[0066] The lid assembly **210** provides an upper boundary to the process volume **212**. The lid assembly **210** typically can be removed or opened to service the processing chamber **202**. In one embodiment, the lid assembly **210** is fabricated from aluminum (Al). The lid assembly **210** includes a pumping plenum **214** formed therein coupled to an external pumping system (not shown). The pumping plenum **214** is utilized to channel gases and processing by-products uniformly from the process volume **212** and out of the processing chamber **202**.

[0067] The lid assembly **210** typically includes an entry port **280** through which process gases provided by the gas source **204** are introduced into the processing chamber **202**. The entry port **280** is also coupled to a cleaning source **282**. The cleaning source **282** typically provides a cleaning agent, such as dissociated fluorine, that is introduced into the processing chamber **202** to remove deposition by-products and films from processing chamber hardware, including the gas distribution plate assembly **218**.

[0068] The gas distribution plate assembly **218** is coupled to an interior side **220** of the lid assembly **210**. The gas distribution plate assembly **218** is typically configured to substantially follow the profile of the glass substrate **240**, for example, polygonal for large area flat panel substrates and circular for wafers. The gas distribution plate assembly **218** includes a perforated area **216** through which process and other gases supplied from the gas source **204** are delivered to the process volume **212**. The perforated area **216** of the gas distribution plate assembly **218** is configured to provide uniform distribution of gases passing through the gas distribution plate assembly **218** into the processing chamber **202**. Gas distribution plates that may be adapted to benefit from the invention are described in commonly assigned U.S. patent application Ser. No. 09/922,219, filed Aug. 8, 2001 by Keller et al., U.S. patent application Ser. Nos. 10/140,324, filed May 6, 2002 by Yim et al., and 10/337,483, filed Jan. 7, 2003 by Blonigan et al., U.S. Pat. No. 6,477,980, issued Nov. 12, 2002 to White et al., U.S. patent application Ser. No. 10/417,592, filed Apr. 16, 2003 by Choi et al., and U.S. patent application Ser. No. 10/823,347, filed on Apr. 12, 2004 by Choi et al., which are hereby incorporated by reference in their entireties.

[0069] The gas distribution plate assembly **218** typically includes a diffuser plate (or distribution plate) **258** suspended from a hanger plate **260**. The diffuser plate **258** and hanger plate **260** may alternatively comprise a single unitary member. A plurality of gas passages **262** are formed through the diffuser plate **258** to allow a predetermined distribution of gas passing through the gas distribution plate assembly **218** and into the process volume **212**. The hanger plate **260** maintains the diffuser plate **258** and the interior side **220** of the lid assembly **210** in a spaced-apart relation, thus defining a plenum **264** therebetween. The plenum **264** allows gases flowing through the lid assembly **210** to uniformly distribute across the width of the diffuser plate **258** so that gas is provided uniformly above the center perforated area **216** and flows with a uniform distribution through the gas passages **262**.

[0070] The diffuser plate **258** is typically fabricated from stainless steel, aluminum (Al), anodized aluminum, nickel (Ni) or other RF conductive material. The diffuser plate **258** could be cast, brazed, forged, hot iso-statically pressed or sintered. The diffuser plate **258** is configured with a thickness that maintains sufficient flatness across the aperture **266** as not to adversely affect substrate processing. The thickness of the diffuser plate **258** is between about 0.8 inch to about 2.0 inches. The diffuser plate **258** could be circular for semiconductor wafer manufacturing or polygonal, such as rectangular, for flat panel display manufacturing.

[0071] **FIG. 3** is a partial sectional view of an exemplary diffuser plate **258** that is described in commonly assigned U.S. patent application Ser. No. 10/417,592, titled "Gas Distribution Plate Assembly for Large Area Plasma Enhanced Chemical Vapor Deposition", filed on Apr. 16, 2003. The diffuser plate **258** includes a first or upstream side **302** facing the lid assembly **210** and an opposing second or downstream side **304** that faces the support assembly **238**. Each gas passage **262** is defined by a first bore **310** coupled by an orifice hole **314** to a second bore **312** that combine to form a fluid path through the gas distribution plate **258**. The first bore **310** extends a length **330** from the upstream side **302** of the gas distribution plate **258** to a bottom **318**. The bottom **318** of the first bore **310** may be tapered, beveled, chamfered or rounded to minimize the flow restriction as gases flow from the first bore into the orifice hole **314**. The first bore **310** generally has a diameter of about 0.093 to about 0.218 inches, and in one embodiment is about 0.156 inches.

[0072] The second bore 312 is formed in the diffuser plate 258 and extends from the downstream side (or end) 304 to a depth 332 of about 0.10 inch to about 2.0 inches. Preferably, the depth 332 is between about 0.1 inch and about 1.0 inch. The diameter 336 of the second bore 312 is generally about 0.1 inch to about 1.0 inch and may be flared at a flaring angle 316 of about 10 degrees to about 50 degrees. Preferably, the diameter 336 is between about 0.1 inch to about 0.5 inch and the flaring angle 316 is between 20 degrees to about 40 degrees. The surface of the second bore 312 is between about 0.05 $inch^2$ to about 10 $inch^2$ and preferably between about 0.05 $inch^2$ to about 5 $inch^2$. The diameter of second bore 312 refers to the diameter intersecting the downstream side 304. An example of diffuser plate, used to process 1500 mm by 1850 mm substrates, has second bores 312 at a diameter of 0.250 inch and at a flaring angle 316 of about 22 degrees. The distances 380 between rims 382 of adjacent second bores 312 are between about 0 inch and about 0.6 inch, preferably between about 0 inch and about 0.4 inch. The diameter of the first bore 310 is usually, but not limited to, being at least equal to or smaller than the diameter of the second bore 312. A bottom 320 of the second bore 312 may be tapered, beveled, chamfered or rounded to minimize the pressure loss of gases flowing out from the orifice hole 314 and into the second bore 312. Moreover, as the proximity of the orifice hole 314 to the downstream side 304 serves to minimize the exposed surface area of the second bore 312 and the downstream side 304 that face the substrate, the downstream area of the diffuser plate 258 exposed to fluorine provided during chamber cleaning is reduced, thereby reducing the occurrence of fluorine contamination of deposited films.

[0073] The orifice hole 314 generally couples the bottom 318 of the first bore 310 and the bottom 320 of the second bore 312. The orifice hole 314 generally has a diameter of about 0.01 inch to about 0.3 inch, preferably about 0.01 inch to about 0.1 inch, and typically has a length 334 of about 0.02 inch to about 1.0 inch, preferably about 0.02 inch to about 0.5 inch. The length 334 and diameter (or other geometric attribute) of the orifice hole 314 is the primary source of back pressure in the plenum 264 which promotes even distribution of gas across the upstream side 302 of the gas distribution plate 258. The orifice hole 314 is typically configured uniformly among the plurality of gas passages 262; however, the restriction through the orifice hole 314 may be configured differently among the gas passages 262 to promote more gas flow through one area of the gas distribution plate 258 relative to another area. For example, the orifice hole 314 may have a larger diameter and/or a shorter length 334 in those gas passages 262, of the gas distribution plate 258, closer to the wall 206 of the processing chamber 202 so that more gas flows through the edges of the perforated area 216 to increase the deposition rate at the perimeter of the glass substrate. The thickness of the diffuser plate is between about 0.8 inch to about 3.0 inches, preferably between about 0.8 inch to about 2.0 inch.

[0074] As the size of substrate continues to grow in the TFT-LCD industry, especially, when the substrate size is at least about 1000 mm by about 1200 mm (or about 1,200,000 mm^2), film thickness and property uniformity for large area plasma-enhanced chemical vapor deposition (PECVD) becomes more problematic. Examples of noticeable uniformity problems include higher deposition rates and more compressive films in the central area of large substrates for some high deposition rate silicon nitride films. The thickness uniformity across the substrate appears "dome shaped" with film in center region thicker than the edge region. The less compressive film in the edge region has higher Si-H content. The manufacturing requirements for TFT-LCD include low Si-H content, for example <15 atomic %, high deposition rate, for example >1500 Å/min, and low thickness non-uniformity, for example <15%, across the substrate. The Si-H content is calculated from FTIR (Fourier Transform Infra-Red) measurement. The larger substrates have worse "dome shape" uniformity issue. The problem could not be eliminated by process recipe modification to meet all requirements. Therefore, the issue needs to be addressed by modifying the gas and/or plasma distribution.

[0075] The process of depositing a thin film in a process chamber is shown in FIG. 4A. The process 400 starts at step 401 by placing a substrate in a process chamber with a diffuser plate. Next at step 402, flow process gas(es) through a diffuser plate toward a substrate supported on a substrate support. Then at step 403, create a plasma between the diffuser plate and the substrate support. At step 404, deposit a thin film on the substrate in the process chamber. FIG. 4B shows a thickness profile of a silicon nitride film across a glass substrate. The size of the substrate is 1500 mm by 1800 mm. The diffuser plate has diffuser holes with design shown in FIG. 3. The diameter of the first bore 310 is 0.156 inch. The length 330 of the first bore 310 is 1.049 inch. The diameter 336 of the second bore 312 is 0.250 inch. The flaring angle 316 of the second bore 312 is 22 degree. The length 332 of the second bore 312 is 0.243 inch. The diameter of the orifice hole 314 is 0.016 inch and the length 334 of the orifice hole 314 is 0.046 inch. The SiN film is deposited using 2800 sccm SiH_4, 9600 sccm NH_3 and 28000 sccm N_2, under 1.5 Torr, and 15000 watts source power. The spacing between the diffuser plate and the support assembly is 1.05 inch. The process temperature is maintained at about 355° C. The deposition rate is averaged to be 2444 Å/min and the thickness uniformity (with 15 mm edge exclusion) is 25.1%, which is higher than the manufacturing specification (<15%). The thickness profile shows a center thick profile, or "dome shape" profile. Table 1 shows the film properties measured from wafers placed on the glass substrate for the above film.

TABLE 1

Measurement of thickness and film properties on a substrate deposited with SiN film.

Measurement location	Thickness (Å)	RI	Stress (E9 Dynes/cm^2)	Si—H (atomic %)	WER (Å/min)
Edge I	5562	1.92	−0.7	12.5	664
Center	8544	1.90	−6.7	4.2	456
Edge II	6434	1.91	−1.2	10.8	665

[0076] Edge I and Edge II represent two extreme ends of the substrate with width at 1800 mm. The refractive index (RI), film stress, Si-H concentration data and wet etch rate (WER) data show a more compressive film near the center region in comparison to the edge region. The Si-H concentrations at the substrate edges are approaching the manufacturing limit of 15%. Wet etch rate is measured by immersing the samples in a BOE (buffered oxide etch) 6:1 solution.

[0077] One theory for the cause of the center to edge non-uniformity problem is excess residual gas between diffuser plate and substrate and in the center region of the substrate that could not be pumped away effectively, which may have caused high deposition rate and more compressive film in the center region of the substrate. A simple test has been designed to see if this theory would stand. As shown in **FIG. 5**, a thermo-resistant tape is used to block of the pumping plenum **214** (shown in **FIG. 2**) near side **501** and side **502** of substrate in a PECVD process chamber. The pumping plenum **214** near the other two sides are left open. Due to this, an asymmetric gas pumping situation was created. If the cause of the "dome shape" problem is due to excess residual gas that could not be pumped away at the edge of the substrate, the use of thermo-resistant tape near two edges of the substrate should worsen the uniformity issue and cause worse uniformity across the substrate. However, little changes has been observed comparing the deposition results between deposition done with 2 pumping plenum blocked and deposition with all pumping channel opened (see Table 2). The diffuser plate used here has the same design and dimensions as the one used for **FIG. 4B** and Table 1. The SiN films in Table 2 are deposited using 3300 sccm SiH_4, 28000 sccm NH_3 and 18000 sccm N_2, under 1.3 Torr, and 11000 watts source power. The spacing between the diffuser plate and the support assembly is 0.6 inch. The process temperature is maintained at about 355° C. Film thickness and properties are measured on location **1**, **2**, **3**, **4** and **5** (as shown in **FIG. 5**) on the substrates. The SiH content shown is Table 2 is measured in atomic %.

TABLE 2

SiN thickness and film properties comparison between deposition with all pumping plenum open and with 2 pumping plenum closed.

	All pumping plenum open				pumping plenum blocked			
Position	Thickness (Å)	RI	Stress (E9 dynes/cm^2)	SiH (%)	Thickness (Å)	RI	Stress (E9 dynes/cm^2)	SiH (%)
1	6156	1.92	−4.6	11.1	5922	1.93	−3.9	11.5
2	7108	1.91	−5.1	8.8	7069	1.92	−5.1	9.1
3	7107	1.91	−5.1	8.5	7107	1.91	−4.8	8.9
4	7052	1.91	−5.0	8.1	7048	1.91	−4.6	8.5
5	6173	1.92	−4.2	10.8	6003	1.92	−3.8	11.2

[0078] The results in Table 2 show little difference between the deposition done with **2** pumping plenum blocked and deposition with all pumping channel opened. In addition, there is little difference between measurement collected at locations **1** and **5**, which should be different if residual gas is the cause of the problem. Therefore, the theory of excess residual gas between diffuser and substrate and in the center region of the substrate not being pumped away effectively is ruled out.

[0079] Another possible cause for the center to edge non-uniformity is plasma non-uniformity. Deposition of films by PECVD depends substantially on the source of the active plasma. Dense chemically reactive plasma can be generated due to hollow cathode effect. The driving force in the RF generation of a hollow cathode discharge is the frequency modulated d.c. voltage Vs (the self-bias voltage) across the space charge sheath at the RF electrode. A RF hollow cathode and oscillation movement of electrons between repelling electric fields, Es, of the opposite sheaths are shown schematically in **FIG. 6A**. An electron emitted from the cathode wall, which could be the walls of the reactive gas passages that are close to the process volume **212**, is accelerated by the electric field Es across the wall sheath "δ". The electron oscillates across the inner space between walls of the electrode owing to the repelling fields of the opposite wall sheaths. The electron loses energy by collisions with the gas and creates more ions. The created ions can be accelerated to the cathode walls thereby enhancing emissions of secondary electrons, which could create additional ions. Overall, the cavities between the cathode walls enhance the electron emission and ionization of the gas. Flared-cone shaped cathode walls, with gas inlet diameter smaller than the gas outlet diameter, are more efficient in ionizing the gas than cylindrical walls. The potential Ez is created due to difference in ionization efficiency between the gas inlet and gas outlet.

[0080] By changing the design of the walls of the hollow cathode cavities, which faces the substrate and are at the downstream ends of the gas diffuser holes (or passages), that are close to the process volume **212** and the arrangement (or density) of the hollow cathode cavities, the gas ionization could be modified to control the film thickness and property uniformity. An example of the walls of the hollow cathode cavities that are close to the process volume **212** is the second bore **312** of **FIG. 3**. The hollow cathode effect mainly occurs in the second bore **312** that faces the process volume **212**. The **FIG. 3** design is merely used as an example. The invention can be applied to other types of hollow cathode cavity designs. Other examples of hollow cathode cavity design include, but not limited to, the designs shown in **FIGS. 6B-6G**. By varying the volume and/or the surface area of the hollow cathode cavity, the plasma ionization rate can be varied.

[0081] Using the design in **FIG. 3** as an example, the volume of second bore (or hollow cathode cavity) **312** can be changed by varying the diameter "D" (or diameter **336** in **FIG. 3**), the depth "d" (or length **332** in **FIG. 3**) and the flaring angle "α" (or flaring angle **316** of **FIG. 3**), as shown in **FIG. 7A**. Changing the diameter, depth and/or the flaring angle would also change the surface area of the second bore **312**. Since the center of substrate has higher deposition rate and is more compressive, higher plasma density is likely the cause. By reducing the bore depth, the diameter, the flaring angle, or a combination of these three parameters from edge to center of the diffuser plate, the plasma density could be reduced in the center region of the substrate to improve the film thickness and film property uniformities. Reducing the cone (or bore) depth, cone diameter, flaring angle also reduces the surface area of the second bore **312**. **FIGS. 7B, 7C** and 7D show 3 diffuser passage (or diffuser hole) designs that are arranged on a diffuser plate shown in **FIG. 7E**. **FIGS. 7B, 7C** and 7D designs have the same cone (or bore) diameter, but the cone (or bore) depth and total cone (bore) surface areas are largest for **FIG. 7B** design and smallest for **FIG. 7D** design. The cone flaring angles have been changed to match the final cone diameter. The cone depth for **FIG. 7B** is 0.7 inch. The cone depth for **FIG. 7C** is 0.5 inch and the cone depth for **FIG. 7D** is 0.325 inch. The smallest region **710** in **FIG. 7E** is 500 mm by 600 mm and the diffuser holes have cone depth 0.325 inch, cone diameter 0.302 inch and flare angel 45° (See **FIG. 7D**). The medium rectangle in **FIG. 7E** is 1000 mm by 1200 mm. The diffuser holes in the region **720** between the medium rectangle and the smallest rectangle have cone depth 0.5 inch, cone diameter 0.302 inch and flare angle 30° (See **FIG. 7C**). The largest rectangle in Figure is 1500 mm by 1800 mm. The diffuser holes in the region **730** between the largest rectangle and the medium rectangle have cone depth 0.7 inch, cone diameter 0.302 inch and flare angle 22° (See **FIG. 7B**) The orifice holes diameters are all 0.03 inch and holes depths are all 0.2 inch for **FIGS. 7B, 7C** and 7D. The thickness of the three diffuser plates are all 1.44 inch. The diameters for first bore **310** of **FIG. 7B, 7C** and 7D are all 0.156 inch and the depth are 0.54 inch (**FIG. 7B**), 0.74 inch (**FIG. 7C**) and 0.915 inch (**FIG. 7C**) respectively.

[0082] **FIG. 8** shows the deposition rate across the substrate. Region I correlates to the area under "0.325 inch depth" cones, while regions II and III correlates to "0.5 inch depth" (region II) and "0.7 inch depth" (region III) respectively. Table 3 shows the measurement of film thickness and properties across the substrate. The SiN film in Table 3 is deposited using 3300 sccm SiH_4, 28000 sccm NH_3 and 18000 sccm N_2, under 1.3 Torr, and 11000 watts source power. The spacing between the diffuser plate and the support assembly is 0.6 inch. The process temperature is maintained at about 355° C. The locations **1**, **2**, **3**, **4** and **5** are the same locations indicated in **FIG. 5**.

TABLE 3

SiN film thickness and property measurement with diffuser plate with 3 regions of varying cone depths.

Position	Cone depth (inch)	Thickness (Å)	RI	Stress (E9 dynes/cm^2)	SiH (atomic %)
1	0.7	6060	1.924	−4.09	9.10
2	0.5	6631	1.921	−5.49	9.66
3	0.325	5659	1.915	−2.02	12.34
4	0.5	6956	1.916	−5.45	9.37
5	0.7	6634	1.917	−4.14	8.83

[0083] The results show that reducing the cone depth and cone surface area reduces the deposition rate. The results also show that reducing the volume and/or surface area of hollow cathode cavity reduces the deposition rate. The reduction of the plasma deposition rate reflects a reduction in plasma ionization rate. Since the change of cone depth and total cone surface area from region I to region II to region III is not smooth, the deposition rates across the substrate shows three regions. Regions I, II and III on the substrate match the diffuser holes regions **710**, **720** and **730**. This indicates that changing the hollow cathode cavity design can change the plasma ionization rate and also the importance of making the changes smooth and gradual.

[0084] There are many ways to gradually change hollow cathode cavities from inner regions of the diffuser plate to the outer regions of the diffuser plate to improve plasma uniformity. One way is to first bend the diffuser plate, which has identical gas diffusing passages across the diffuser plate, to a pre-determined curvature and afterwards machine out the curvature to leave the surface flat. **FIG. 9A** shows the process flow of this concept. The process starts by bending the diffuser plate to make it convex at step **901**, followed by machining out the curvature of the convex diffuser plate to make the diffuser plate surface flat at step **902**. **FIG. 9B** shows a schematic drawing of a convex diffuser plate with an exemplary diffuser hole (or gas passage) **911** at the edge (and outer region) and an exemplary diffuser hole **912** in the center (and inner region) as diffuser holes. The diffuser holes **911** and **912** are identical before the bending process and are simplified drawings of diffuser holes as shown in **FIGS. 3 and** 7A. However, the invention can be used for any diffuser holes designs. The design in **FIG. 3** is merely used for example. Diffuser plate downstream side **304** faces the process volume **212**. The gradual changing distance between the downstream side **913** surface and the flat **914** surface (dotted due to its non-existence) shows the curvature. The edge diffuser cone **915** and center diffuser cone **916** are identical in size and shape prior to the bending process. **FIG. 9C** shows the schematic drawing of a diffuser plate after the curvature has been machined out. The surface facing the process volume **212** is machined to **914** (a flat surface), leaving center cone **918** significantly shorter than the edge cone **917**. Since the change of the cone size (volume and/or surface area) is created by bending the diffuser plate followed by machining out the curvature, the change of the cone size (volume and/or surface area) from center to edge is gradual. The center cone **918** would have diameter "D" and depth "d" smaller than the edge cone **917**. The definition of cone diameter "D" and cone depth "d" can be found in the description of **FIG. 7A**.

[0085] **FIG. 9D** shows the depth "d" of the second bore **312** (or cone) that extend to the downstream side of an exemplary diffuser plate, which is used to process 1500 mm by 1850 mm substrates. The diffuser plate has diffuser holes with design shown in **FIG. 7A**. The diameter of the first bore **310** is 0.156 inch. The length **330** of the first bore **310** is 1.049 inch. The diameter **336** of the second bore **312** is 0.250 inch. The flaring angle **316** of the second bore **312** is 22 degree. The length **332** of the second bore **312** is 0.243 inch. The diameter of the orifice hole **314** is 0.016 inch and the length **334** of the orifice hole **314** is 0.046 inch. The measurement of depths of the second bores in **FIG. 9D** shows a gradual increasing of bore depth **332** (or "d" in **FIG. 7A**) from center of the diffuser plate to the edge of the diffuser plate. Due to the bending and machining processes, the diameter **336** (or "D" in **FIG. 7A**) of the second bore **312** also gradually increases from center of the diffuser plate to the edge of the diffuser plate.

[0086] **FIG. 9E** shows the thickness distribution across a substrate deposited with SiN film under a diffuser plate with a design described in **FIGS. 9B, 9C** and 9D. The size of substrate is 1500 mm by 1850 mm, which is only slightly larger than the size of substrate (1500 mm by 1800 mm) in **FIG. 4B** and Table 1. Typically, the diffuser plate sizes scale with the substrate sizes. The diffuser plate used to process 1500 mm by 1850 mm substrates is about 1530 mm by 1860 mm, which is slightly larger than the diffuser plate used to process 1500 mm by 1800 mm substrates (diffuser plate about 1530 mm by 1829 mm). The thickness uniformity is improved to 5.0%, which is much smaller than 25.1% for film in **FIG. 4B**. Table 4 shows the film property distribution across the substrate. The diffuser plate has diffuser holes with design shown in FIG. 7A. The diameter of the first bore **310** is 0.156 inch. The length **330** of the first bore **310** is 1.049 inch. The diameter **336** of the second bore **312** is 0.250 inch. The flaring angle **316** of the second bore **312** is 22 degree. The length **332** of the second bore **312** is 0.243 inch. The diameter of the orifice hole **314** is 0.016 inch and the length **334** of the orifice hole **314** is 0.046 inch. The SiN films in **FIG. 9E** and Table 4 are deposited using 2800 sccm SiH_4, 9600 sccm NH_3 and 28000 sccm N_2, under 1.5 Torr, and 15000 watts source power. The spacing between the diffuser plate and the support assembly is 1.05 inch. The process temperature is maintained at about 355° C. Edge I and Edge II represent two extreme ends of the substrate, as described in Table 1 measurement. The film thickness and property data in Table 4 show much smaller center to edge variation compared to the data in Table 1.

TABLE 4

SiN film thickness and property measurement using a diffuser plate with gradually varied bore depths and diameters from center to edge for a 1500 mm by 1850 mm substrate.

Measurement location	Thickness (Å)	RI	Stress (E9 Dynes/cm^2)	Si—H (atomic %)	WER (Å/min)
Edge I	6405	1.92	−0.7	13.3	451
Center	6437	1.91	−1.8	12.7	371
Edge II	6428	1.92	−1.2	11.9	427

[0087] Comparing the data in Table 4 to the data in Table 1, which are collected from deposition with a diffuser plate with the same diameters and depths of second bore **312** across the diffuser plate, the variation of thickness, stress, Si-H content and wet etch rate (WER) are all much less for the data in Table 4, which is collected from deposition with a diffuser plate with gradually increasing diameters and depths of second bore **312** from the center to the edge of the diffuser plate. The results show that uniformity for thickness and film properties can be greatly improved by gradually increasing the diameters and depths of the bores, which extend to the downstream side of the diffuser plate, from center to edge. The wet etch rates in the tables are measured by immersing the samples in a BOE 6:1 solution.

[0088] **FIG. 9F** shows the depth "d" measurement of the second bore **312** across an exemplary diffuser plate, which is used to process 1870 mm by 2200 mm substrates Curve **960** shows an example of an ideal bore depth distribution the diffuser plate. The measurement of depths of the bores in **FIG. 9F** shows a gradual increasing of bore depth from center of the diffuser plate to the edge of the diffuser plate. The downstream bore diameter would also gradually increase from center of the diffuser plate to the edge of the diffuser plate.

[0089] **FIG. 9G** shows the thickness distribution across a substrate deposited with SiN film under a diffuser plate with a design similar to the one described in **FIGS. 9B, 9C** and 9F. The size of the substrate is 1870 mm by 2200 mm. Table 5 shows the film property distribution across the substrate. The diffuser plate has diffuser holes with design shown in **FIG. 7A**. The diameter of the first bore **310** is 0.156 inch. The length **330** of the first bore **310** is 0.915 inch. The diameter **336** of the second bore **312** is 0.302 inch. The flaring angle **316** of the second bore 312 is 22 degree. The length **332** of the second bore **312** is 0.377 inch. The diameter of the orifice hole **314** is 0.018 inch and the length **334** of the orifice hole **314** is 0.046 inch. The SiN films in Table 5 are deposited using 5550 sccm SiH_4, 24700 sccm NH_3 and 61700 sccm N_2, under 1.5 Torr, and 19000 watts source power. The spacing between the diffuser plate and the support assembly is 1.0 inch. The process temperature is maintained at about 350° C. Edge I and Edge II represent two extreme ends of the substrate, as described in Table 1 measurement. The film thickness and property data in Table 5 show much smaller center to edge variation compared to the data in Table 1. The thickness uniformity is 9.9%, which is much better than 25.1% for film in **FIG. 4B**. The data shown in **FIG. 4B** and Table 1 are film thickness and property data on smaller substrate (1500 mm by 1800 mm), compared to the substrate (1870 mm by 2200 mm) for data in **FIG. 9G** and Table 5. Thickness and property uniformities are expected to be worse for larger substrate. The uniformity of 9.9% and the improved film property data in Table 5 by the new design show that the new design, with gradual increasing diameters and depths of diffuser bores extended to the downstream side of the diffuser plate, greatly improves the plasma uniformity and process uniformity.

TABLE 5

SiN film thickness and property measurement using a diffuser plate with gradually varied bore depths and diameters from center to edge for an 1870 mm by 2200 mm substrate.

Measurement location	Thickness (Å)	RI	Stress (E9 Dynes/cm^2)	Si—H (atomic %)	WER (Å/min)
Edge I	5814	1.94	−0.3	16.4	509
Center	5826	1.93	0.8	17.3	716
Edge II	5914	1.92	−0.6	13.9	644

[0090] Although the exemplary diffuser plate described here is rectangular, the invention applies to diffuser plate of other shapes and sizes. One thing to note is that the convex downstream surface does not have to be machined to be completely flat across the entire surface. As long as the diameters and depths of the bores are increased gradually from center to edge of the diffuser plate, the edge of the diffuser plate could be left un-flattened.

[0091] There are also many ways to create curvature of the diffuser plate. One way is to thermally treat the diffuser plate at a temperature that the diffuser plate softens, such as a >400° C. temperature for aluminum, for a period of time by supporter only the edge of the diffuser plate. When the metal diffuser plate softens under the high temperature treatment, the gravity would pull center of the diffuser plate down and the diffuser plate would become curved. **FIG. 10A** shows the process flow **1000** of such thermal treatment. First, at step **1001** place the diffuser plate, which already has diffuser holes in it, in an environment **1005** or chamber that could be thermally controlled and place the diffuser plate **1010** on a diffuser plate support **1020** that only support the edge of the diffuser plate (See **FIG. 10B**). The diffuser plate facing down is the downstream side **304** of the diffuser plate. Afterwards at step **1002**, raise the temperature of the environment and treat the diffuser plate at a thermal condition at a temperature that the diffuser plate softens. One embodiment is to keep the thermal environment at a constant treatment temperature (isothermal), once the constant treatment temperature has been reached. After the curvature of the diffuser plate has reached the desired curvature, stop the thermal treatment process at step **1003**. Note that in the thermal environment, optional diffuser support **1030** could be placed under diffuser plate **1010** at support height **1035** lower than the support height **1025** of diffuser plate support **1020** and at a support distance **1037** shorter than the support distance **1027** of support **1020**. The optional diffuser support **1030** could help determine the diffuser curvature and could be made of elastic materials that could withstand temperature greater than 400° C. (the same temperature as the thermal conditioning temperature) and would not damage the diffuser plate surface. **FIG. 10C** shows that the curved diffuser plate **1010** resting on the diffuser plate supports **1020** and **1030** after the bending process.

[0092] Another way to create curvature is to use vacuum to smoothly bend the diffuser plate to a convex shape. **FIG. 11 A** shows the process flow **1100** of such bending by vacuum process. First, at step **1101** place the diffuser plate, which already has diffuser holes in it and the downstream side **304** facing down, on a vacuum assembly **1105** and seal the upstream side **302** of the diffuser plate with a cover. The material used to cover (or seal) the upstream end of the diffuser plate must be strong enough to keep its integrity under vacuum. The vacuum assembly only supports the diffuser plate at the edge (See **FIG. 11B**) by diffuser plate support **1120**. The vacuum assembly **1105** is configured to have a pump channel **1150** to pull vacuum in the volume **1115** between the diffuser plate and the vacuum assembly **1105** when the upstream end of the diffuser plate is covered. The pump channel **1150** in **FIGS. 11B and 11C** are merely used to demonstrate the concept. There could be more than one pumping plenum placed at different locations in the vacuum assembly **1105**. Afterwards at step **1102**, pull vacuum in the volume **1115** between the diffuser plate and the diffuser plate holder. When the curvature of the diffuser plate has reached the desired curvature, stop the vacuuming process at step **1103** and restore the pressure of the volume **1115** between the diffuser plate and the vacuum assembly to be equal to the surrounding environment **1140** to allow the diffuser plate to be removed from the vacuum assembly **1105**. Note that in the vacuum assembly, optional diffuser support **1130** could be placed under diffuser plate **1110** at support height **1135** lower than the support height **1125** of the diffuser plate support **1120** and at a support distance **1137** shorter than the support distance **1127** of diffuser plate support **1120**. The optional support could help determine the diffuser curvature and could be made of materials, such as rubber, that would not damage the diffuser plate surface. **FIG. 11C** shows that the curved diffuser plate **1110** resting on the diffuser plate supports **1120** and **1130** after the bending process.

[0093] Another way to change the second bore (**312** in **FIG. 3**) depth, cone diameter, cone flaring angle or a combination of these three parameters is by drilling the diffuser holes with varying cone depth, cone diameter or cone flaring angles from center of the diffuser plate to the edge of the diffuser plate. The drilling can be achieved by computer numerically controlled (CNC) machining. **FIG. 12A** shows the process flow of such a process **1200**. The process **1200** starts at step **1230** by creating bores that extend to the downstream side of a diffuser plate with gradually increasing bore depths and/or bore diameters from center to edge of the diffuser plate. The flaring angle can also be varied from center to edge of the diffuser plate. Next at step **1240**, the process is completed by creating the remaining portions of the gas passages of the diffuser plate. The downstream cones can be created by using drill tools. If drill tools with the same flaring angle are used across the diffuser plate, the cone flaring angles would stay constant and cone depth and cone diameter are varied. The cone diameter would be determined by the flaring angle and cone depth. The important thing is to vary the cone depth smoothly and gradually to ensure smooth deposition thickness and film property change across the substrate. **FIG. 12B** shows an example of varying cone depths and cone diameters. Diffuser hole **1201** is near the center of the diffuser plate and has the smallest cone depth **1211** and cone diameter **1221**. Diffuser hole **1202** is between the center and edge of the diffuser plate and has the medium cone depth **1212** and cone diameter **1222**. Diffuser hole **1203** is near the edge of the diffuser plate and has the largest cone depth **1213** and cone diameter **1223**. The cone flaring angle of all diffuser holes are the same for the design in **FIG. 12B**. However, it is possible to optimize deposition uniformity by varying the cone design across the diffuser plate by varying both the cone diameters, cone depths and flaring angles. Changing the cone depth, cone diameter and cone flaring angle affects the total cone surface area, which also affects the hollow cathode effect. Smaller cone surface area lowers the plasma ionization efficiency.

[0094] Yet another way to change the second bore (**312** in **FIG. 3**) depth ("d"), and bore diameter ("D") is by drilling identical diffuser holes across the diffuser plate (see **FIG. 12C**). In **FIG. 12C**, the gas diffuser hole **1251** at the edge (at outer region) of the diffuser plate is identical to the gas diffuser hole **1252** at the center (at inner region) of the diffuser plate. The downstream bore **1255** is also identical to downstream bore **1256**. The downstream surface **1254** of gas diffuser plate is initially flat. Afterwards, machine downstream side of the diffuser plate to make a concave shape with center thinner than the edge. The machining can be achieved by computer numerically controlled machining or other types of controlled machining to make the machining process repeatable. After machining the downstream surface **1254** to a concave shape (downstream surface **1259**), the downstream bore **1258** at the center (an inner region) of the diffuser plate has smaller diameter ("D") and smaller length ("d") than the downstream bore **1257** at the edge (an outer region) of the diffuser plate. The diffuser plate can be left the way it is as in **FIG. 12D**, or downstream surface **1259** can be pulled flat as shown in **FIG. 12E**, or to other curvatures (not shown), to be used in a process chamber to achieve desired film results.

[0095] Yet another way to change the second bore (**312** in **FIG. 3**) depth ("d"), and bore diameter ("D") is by bending the diffuser plate without any diffuser hole into concave shape (See **FIG. 12F**). In **FIG. 12F**, the downstream surface labeled downstream surface **1269**. Afterwards, drill the downstream bores to the same depth using the same type of drill from a fictitious flat surface **1264** (See **FIG. 12G**). Although downstream bore **1268** at the center of the diffuser plate is drilled to the same depth from the fictitious flat surface **1264** as the downstream bore **1267**, the diameter and length of the downstream bore **1268** are smaller than the diameter and length of the downstream bore **1267**. The rest of the diffuser holes, (e.g. item nos. **1261** and **1262**) which include orifice holes **1265**, upstream bores **1263**, and connecting bottoms, are machined to complete the diffuser holes. All orifice holes and upstream bores should have identical diameters, although it is not necessary. The diameters and lengths of the orifice holes should be kept the same across the diffuser plate (as shown in **FIG. 12G**). The orifice holes controls the back pressure. By keeping the diameters and the lengths of the orifice holes the same across the diffuser plate, the back pressure, which affects the gas flow, can be kept the same across the diffuser plate. The diffuser plate can be left the way it is as in **FIG. 12G**, or downstream surface **1269** can be pulled flat as shown in **FIG. 12H**, or to other curvatures (not shown), to be used in a process chamber to achieve desired film results.

[0096] The changes of diameters and/or lengths of the hollow cathode cavities do not have to be perfectly continuous from center of the diffuser plate to the edge of the diffuser plate, as long the changes are smooth and gradual. It can be accomplished by a number of uniform zones arranged in a concentric pattern as long as the change from zone to zone is sufficiently small. But, there need to be an overall increase of size (volume and/or surface area) of hollow cathode cavity from the center of the diffuser plate to the edge of the diffuser plate. **FIG. 12I** shows a schematic plot of bottom view (looking down at the downstream side) of a diffuser plate. The diffuser plate is divided into N concentric zones. Concentric zones are defined as areas between an inner and an outer boundaries, which both have the same geometric shapes as the overall shape of the diffuser plate. Within each zone, the diffuser holes are identical. From zone **1** to zone N, the hollow cathode cavity gradually increase in size (volume and/or surface area). The increase can be accomplished by increase of hollow cathode cavity diameter, length, flaring angle, or a combination of these parameters.

[0097] The increase of diameters and/or lengths of the hollow cathode cavities from center to edge of the diffuser plate also do not have to apply to all diffuser holes, as long as there is an overall increase in the size (volume and/or surface area) of hollow cathode cavities per downstream diffuser plate surface area of the hollow cathode cavities. For example, some diffuser holes could be kept the same throughout the diffuser plate, while the rest of the diffuser holes have a gradual increase in the sizes (volumes and/or surface areas) of the hollow cathode cavities. In another example, the diffuser holes have a gradual increase in sizes (volumes and/or surface areas) of the hollow cathode cavities, while there are some small hollow cathode cavities at the edge of the diffuser plate, as shown in **FIG. 12J**. Yet in another example, most of the hollow cathode cavities are uniform across the diffuser plate, while there are a few larger hollow cathode cavities towards the edge of the diffuser plate, as shown in **FIG. 12K**.

[0098] We can define the hollow cathode cavity volume density as the volumes of the hollow cathode cavities per downstream diffuser plate surface area of the hollow cathode cavities. Similarly, we can define the hollow cathode cavity surface area density of the hollow cathode cavity as the total surface areas of the hollow cathode cavities per downstream diffuser plate surface area of the hollow cathode cavities. The results above show that plasma and process uniformities can be improved by gradual increase in either the hollow cathode cavity volume density or the hollow cathode cavity surface area density of the hollow cathode cavities from the inner regions to the outer regions of the diffuser plate, or from center to edge of the diffuser plate.

[0099] Another way to change the film deposition thickness and property uniformity is by changing the diffuser holes density across the diffuser plate, while keeping the diffuser holes identical. The density of diffuser holes is calculated by dividing the total surface of holes of second bore **312** intersecting the downstream side **304** by the total surface of downstream side **304** of the diffuser plate in the measured region. The density of diffuser holes can be varied from about 10% to about 100%, and preferably varied from 30% to about 100%. To reduce the "dome shape" problem, the diffuser holes density should be lowered in the inner region, compared to the outer region, to reduce the plasma density in the inner region. The density changes from the inner region to the outer region should be gradual and smooth to ensure uniform and smooth deposition and film property profiles. **FIG. 13** shows the gradual change of diffuser holes density from low in the center (region A) to high at the edge (region B). The lower density of diffuser holes in the center region would reduce the plasma density in the center region and reduce the "dome shape" problem. The arrangement of the diffuser holes in **FIG. 13** is merely used to demonstrate the increasing diffuser holes densities from center to edge. The invention applies to any diffuser holes arrangement and patterns. The density change concept can also be combined with the diffuser hole design change to improve center to edge uniformity. When the density of the gas passages is varied to achieve the plasma uniformity, the spacing of hollow cathode cavities at the down stream end could exceed 0.6 inch.

[0100] The inventive concept of gradual increase of hollow cathode cavity size (volume and/or surface area) from the center of the diffuser plate to the edge of the diffuser plate can be accomplished by a combination of the one of the hollow cathode cavity size (volume and/or surface area) and shape variation, with or without the diffuser hole density variation, with one of the diffuser plate bending method, and with one of the hollow cathode cavity machining methods applicable. For example, the concept of increasing density of diffuser holes from the center to the edge of the diffuser plate can be used increasing the diameter of the hollow cathode cavity (or downstream bore) from the center to the edge of the diffuser plate. The diffuser plate could be kept flat and the diffuser holes are drilled by CNC method. The combination is numerous. Therefore, the concept is very capable of meeting the film thickness and property uniformity requirements.

[0101] Up to this point, the various embodiments of the invention are mainly described to increase the diameters and lengths of the hollow cathode cavities from center of the diffuser plate to the edge of the diffuser plate to improve the plasma uniformity across the substrate. There are situations that might require the diameter and the lengths of the hollow cathode cavities to decrease from the center of the diffuser plate to the edge of the diffuser plate. For example, the power source might be lower near the center of the substrate and the hollow cathode cavities need to be larger to compensate for the lower power source. The concept of the invention, therefore, applies to decreasing the sizes (volumes and/or areas) hollow cathode cavities from the center of the diffuser plate to the edge of the diffuser plate.

[0102] The concept of the invention applies to any design of gas diffuser holes, which includes any design of hollow cathode cavity, and any shapes/sizes of gas diffuser plates. The concept of the invention applies to a diffuser plate that utilizes multiple designs of gas diffuser holes, which include multiple designs of hollow cathode cavities. The concept of the invention applies to diffuser plate of any curvatures and diffuser plate made of any materials, for example, aluminum (Al), tungsten (W), chromium (Cr), tantalum (Ta), or combinations thereof, among others, and by any methods, for example, cast, brazed, forged, hot iso-statically pressed or sintered. The concept of the invention also applies to diffuser plate made of multiple layers of materials that are pressed or glued together. In addition, the concept of the invention can be used in a chamber that could be in a cluster system, a stand-alone system, an in-line system, or any systems that are applicable.

[0103] Although several preferred embodiments which incorporate the teachings of the present invention have been shown and described in detail, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.

What is claimed is:

1. A gas distribution plate assembly for a plasma processing chamber, comprising:

a diffuser plate having an upstream side, a downstream side, and has an array of gas passages passing between the upstream and downstream sides of the diffuser plate, wherein the array of gas passages has:

a first gas passage having a first hollow cathode cavity that is proximate to the downstream side, wherein the hollow cathode cavity has a wall that has first surface area; and

a second gas passage that is positioned closer to a center point of the diffuser plate than the first gas passage and has a second hollow cathode cavity that is proximate to the downstream side, wherein the second hollow cathode cavity has a wall that a second surface area and the second surface area is greater than the first surface area.

2. The gas distribution plate assembly of claim 1, wherein the volume of the first hollow cathode cavity is less than the volume of the second hollow cathode cavity.

3. The gas distribution plate assembly of claim 1, wherein the hollow cathode cavities are cone or cylinder shaped, and the cone or cylinder shaped hollow cathode cavities have a diameter formed at the downstream side and a depth.

4. The gas distribution plate assembly of claim 3, wherein the diameter formed at the downstream side is between about 0.1 inch to about 1.0 inch.

5. The gas distribution plate assembly of claim 3, wherein the depth is between about 0.1 inch to about 2.0 inch.

6. The gas distribution plate assembly of claim 3, wherein the cones have a flaring angle that is between about 10 degrees to about 50 degrees.

7. The gas distribution plate assembly of claim 1, wherein the hollow cathode cavities are cone shaped and the cone shaped cavities have:

a diameter formed at the downstream side that is between about 0.1 inch and about 1.0 inch;

a depth that is between about 0.1 inch and about 2.0 inch; and

a flaring angle of the cones are between about 10 degrees and about 50 degrees.

8. The gas distribution plate assembly of claim 1, wherein a spacing between the downstream ends of the hollow cathode cavities of adjacent gas passages is at most about 0.6 inch.

9. The gas distribution plate assembly of claim 1, wherein the diffuser plate is rectangular.

10. The gas distribution plate assembly of claim 1, wherein the surface area of the downstream surface of the gas distribution plate is at least 1,200,000 mm^2.

11. The gas distribution plate assembly of claim 3, wherein the diameter or the lengths or a combination of both of the cones or cylinders gradually increases from center to edge of the diffuser plate.

12. A gas distribution plate assembly for a plasma processing chamber, comprising:

a diffuser plate having an upstream side, a downstream side, and has an array of gas passages passing between the upstream and downstream sides of the diffuser plate, wherein the array of gas passages has:

a plurality of first gas passages having a first hollow cathode cavity that each have a first diameter that is in contact with the downstream side and a first depth; and

a plurality of second gas passages that are positioned closer to a center point of the diffuser plate than the plurality of first gas passages and each of the plurality of second gas passages have a second hollow cathode cavity that has a second diameter that is in contact with the downstream side and a second depth, wherein the second diameter is larger than the first diameter or the second depth is larger than the first depth.

13. The gas distribution plate assembly of claim 12, wherein the diffuser plate is rectangular.

14. The gas distribution plate assembly of claim 12, wherein the surface area of the downstream surface of the gas distribution plate is at least 1,200,000 mm^2.

15. A gas distribution plate assembly for a plasma processing chamber, comprising:

a diffuser plate having an upstream side, a downstream side, and has an array of gas passages passing between the upstream and downstream sides of the diffuser plate, wherein the array of gas passages has:

a plurality of first gas passages having a first hollow cathode cavity that each have a first diameter that is in contact with the downstream side, a first flaring angle, and a first depth; and

a plurality of second gas passages that have a second hollow cathode cavity that has a second diameter that is in contact with the downstream side, a second flaring angle and a second depth, wherein the second diameter is greater than the first diameter, the second flaring angle is greater than the first flaring angle, or the second depth is greater than the first depth.

16. The gas distribution plate assembly of claim 15, wherein the diffuser plate is rectangular.

17. The gas distribution plate assembly of claim 15, wherein the surface area of the downstream surface of the gas distribution plate is at least 1,200,000 mm^2.

18. The gas distribution plate assembly of claim 15, wherein the first and second diameters are between about 0.1 inch and about 1.0 inch in size.

19. The gas distribution plate assembly of claim 15, wherein the first and second depths are between about 0.1 inch and about 2.0 inch.

20. The gas distribution plate assembly of claim 15, wherein the first and second flaring angles are between about 10 degrees to about 50 degrees.

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