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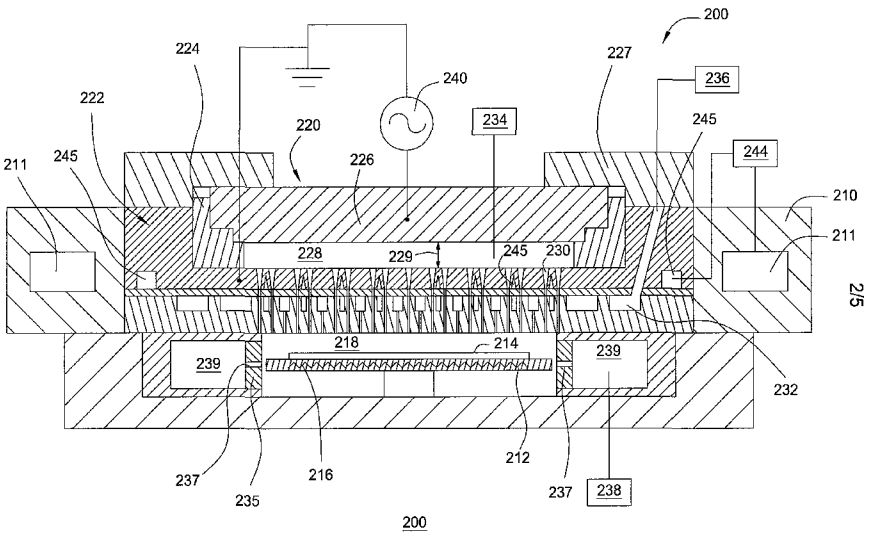

FIG. 2

(57) Abstract: Embodiments of the present invention provide method and apparatus for performing metal HVPE or MOCVD process using radicals from a plasma. One embodiment of the present invention provides a processing chamber having a gas distribution assembly configured to generate a plasma and provide one or more radical species to a processing volume while shielding electrical field of the plasma from the processing volume. In one embodiment the gas distribution assembly has a plurality of passages defined by a bore connected to a cone, wherein the aspect ratio of the bore is adjusted to allow passage of radicals in the plasma and retain the electrical field of the plasma.

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HOLLOW CATHODE SHOWERHEAD

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] Embodiments of the present invention relates to apparatus and method for processing substrates. Particularly, embodiments of the present invention provide apparatus and method for performing thermal activated chemical vapor deposition processes using radicals from a plasma. Embodiments of the present invention also provide apparatus and method for a downstream cleaning process.

Description of the Related Art

[0002] Group III metal nitride semiconductors are finding greater importance in the development and fabrication of a variety of semiconductor devices, such as short wavelength light emitting diodes (LEDs), laser diodes (LDs), and electronic devices including high power, high frequency, high temperature transistors and integrated circuits. Light emitting diodes (LEDs) and laser diodes (LDs) are fabricated by depositing group-Ill nitrides on substrates. Group-Ill nitrides can be deposited by hydride vapor phase epitaxy (HVPE), metal organic chemical vapor deposition (MOCVD), chemical vapor deposition (CVD), and/or physical vapor deposition (PVD) on aluminum oxide containing substrates, such as sapphire substrates.

[0003] Traditionally, nitrogen source is provided from heated ammonia (NH_3) gas when forming Group-Ill metal nitride film by HVPE or MOCVD. The temperature required for ammonia to crack and generate nitrogen is high and somewhat limits reaction kinetics as well as physical and chemical properties of source gases. Additionally, a small amount of undesirable hydrogen in ammonia may also be formed in the metal nitride film. Ammonia is also fairly expensive compare to other nitrogen source, such as nitrogen gas.

[0004] Embodiments of the present invention provide solutions to use nitrogen gas a nitrogen source in forming Group-Ill metal nitride by HVPE or MOCVD process, thus, reducing cost of ownership in producing LED, LD, or other devices.

SUMMARY OF THE INVENTION

[0005] The present invention generally provides apparatus and methods for forming LED/LD structures. Particularly, embodiments of the present invention relate to apparatus and method for performing thermal activated chemical vapor deposition using radicals from a plasma, for example, for forming Group-Ill metal nitride layer for devices such as light emitting diodes (LEDs) or laser diodes (LDs) using nitrogen radicals from a plasma. Embodiments of the present invention may also apply to a downstream cleaning process.

[0006] One embodiment of the present invention provides a chamber for processing one or more substrates comprising a chamber body defining a processing volume, a susceptor disposed in the processing volume and configured to support the one or more substrates, a gas distribution assembly disposed over the susceptor, wherein the gas distribution assembly is configured to generate a plasma and provide one or more radical species from the plasma to the processing volume while shielding electrical field of the plasma from the processing volume, a RF (radial frequency) power source coupled to the gas distribution assembly, a first reactant gas source coupled to the gas distribution assembly, and a second reactant gas source in fluid communication with the processing volume.

[0007] Another embodiment of the present invention provides a gas distribution assembly for providing radicals of a reactant gas to a processing region comprising a first electrode having a plurality of first passages connecting a first side of the first electrode and a second side of the electrode, wherein the first side of the first electrode is configured to face the processing region, and each first passage has a narrow opening on the first side and a wide opening on the second side, a second electrode substantially parallel to the first electrode, wherein the second side of the first electrode faces the second electrode, and a plasma generating volume is

defined between the first and second electrodes, and an insulator disposed between the first and second electrodes near perimeters of the first and second electrodes and providing electrical insulation between the first and second electrodes.

[0008] Yet another embodiment of the present invention provides a method for processing one or more substrates comprising disposing the one or more substrates on a susceptor disposed in a processing volume of a processing chamber, wherein the processing chamber comprises a gas distribution assembly disposed over the susceptor, and the gas distribution assembly has a plasma generating volume, flowing a first reactive gas to the plasma generating volume of the gas distribution chamber, igniting a plasma within the plasma generating volume to generate radicals of the first reactive gas, introducing the radials of the first reactive gas to the processing volume, flowing a second reactive gas to the processing volume, and forming a film over the one or more substrate, wherein the film is a reactive product of the first reactive gas and the second reactive gas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0010] Figure 1 is a schematic view of a processing chamber in accordance with one embodiment of the present invention.

[0011] Figure 2 is a schematic sectional side view of a MOCVD chamber in accordance with one embodiment of the present invention.

[0012] Figure 3A is a partial sectional side view of a cathode for a gas distribution assembly in accordance with one embodiment of the present invention.

[0013] Figure 3B is a top view of the cathode of Figure 3A.

[0014] Figure 3C is a bottom view of the cathode of Figure 3A showing cooling channels.

[0015] Figure 3D is another top view of the cathode of Figure 3A showing channels for a second gas source.

[0016] Figure 4 is a sectional view of a HVPE chamber in accordance with one embodiment of the present invention.

[0017] Figure 5 is a partial sectional view of a cathode of a gas distribution assembly in the HVPE chamber of Figure 4.

[0018] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially utilized on other embodiments without specific recitation.

DETAILED DESCRIPTION

[0019] Embodiments of the present invention relates to performing thermal activated chemical vapor deposition processes using radicals from a plasma. Embodiments of the present invention relate to the manufacture of devices such as light emitting diodes (LEDs) or laser diodes (LDs). More particularly, embodiments of the present invention relate to apparatus and method for forming Group-III metal nitride films by HVPE or MOCVD using nitrogen radicals from a plasma. Embodiments of the present invention also relate to forming oxide film using oxygen radicals from an oxygen plasma. Embodiments of the present invention may also be used to generate a plasma of pure compound to provide radicals for a chemical vapor deposition process, for example, for generating AsH_3 plasma to provide As radicals for mixing with trimethylgallium (TMG).

[0020] One embodiment of the present invention provides a processing chamber having a gas distribution assembly configured to generate a plasma and provide one

or more radical species to a processing volume while shielding electrical field of the plasma from the processing volume. By quenching radial species from a plasma, embodiments of the present invention enables conventional thermal activated vapor deposition to be performed at a lower temperature. In one embodiment the gas distribution assembly has a plurality of passages defined by a bore connected to a cone, wherein the aspect ratio of the bore is adjusted to allow passage of radicals in the plasma and retain the electrical field of the plasma.

[0021] Figure 1 is a schematic view of a processing chamber 1 in accordance with one embodiment of the present invention. The processing chamber 1 is configured to form metal nitride films by a vapor deposition method with at least one precursor generated from a plasma.

[0022] The processing chamber 1 comprises a chamber body 10, and a susceptor 12 and a gas distribution assembly 20 disposed in the chamber body 10.

[0023] The susceptor 12 is configured to support one or more substrates 14 to expose the one or more substrates 14 to precursors in a processing volume 18 to be processed. In one embodiment, the susceptor 12 comprises a heater 16 configured to heat the one or more substrates 14 to a temperature required by the process being performed.

[0024] The gas distribution assembly 20 comprises a first electrode 22, a second electrode 26 and an insulator 24 disposed between the first electrode 22 and the second electrode 26. The first electrode 22, insulator 24 and the second electrode 26 defines an inner volume 28. In one embodiment, the first electrode 22 is coupled to a RF (radio frequency) ground, the second electrode 26 is coupled to a RF power source 40, and the insulator 24 electrically insulates the first electrode 22 from the second electrode 26.

[0025] A first gas source 34 is connected the inner volume 28 to provide one or more reactive gases to the inner volume 28. A capacitive plasma can be generated in the inner volume 28 when an RF power is applied to the second electrode 26.

[0026] The first electrode 22 is disposed between the second electrode 26 and the susceptor 12 shielding the susceptor 12 and the one or more substrates 14 from the RF field of the second electrode 26 during plasma generation.

[0027] The first electrode 22 has a plurality of first passages 30 formed therethrough. Each passage 30 connects the inner volume 28 to the processing volume 18. In one embodiment, the plurality of first passages 30 are evenly distributed across a surface area of the first electrode 22 corresponding to a surface area of the susceptor 12.

[0028] The processing chamber 1 further comprises a vacuum pump 38 configured to pump out the processing volume 18 and obtain a desired pressure level in the processing volume 18. During processing, the vacuum pump 38 provides a negative pressure in the processing volume 18 relative to the inner volume 28 of the gas distribution assembly 20, thus, allowing the species in the inner volume 28 to flow to the processing volume 18.

[0029] In one embodiment, the gas distribution assembly 20 is configured to generate a plasma 42 within the inner volume 28 and the first passage 30 to disassociate a source gas and provide radials in the plasma to the processing volume 18 while shielding the RF field of the plasma from the processing volume 18. In one embodiment, shielding the electric filed of the plasma may be achieved by providing one or more baffle features in each passage 30 which connects the inner volume 28 and the processing volume 18.

[0030] In one embodiment, the passage 30 provides a battle by having a wider opening towards the inner volume 28 and a narrower opening toward the external, in this case the processing volume 18.

[0031] In one embodiment, the passage 30 comprises a wide channel 30a connected to a narrow bore 30b and an aspect ratio of the narrow bore 30b is adjusted to retain the plasma within the inner volume 28. In one embodiment, the wide channel 30a may have a cone shape. As shown in Figure 1, the sheath of the

plasma 42 exists in the inner volume 28 and the wide channel 30a. The narrow bore 30b is configured to provide a baffle to retain the plasma within. The diameter, length, or aspect ratio of the length and diameter may be affected by pressure, flow rate, species in the plasma, or other effectors. In one embodiment, an aspect ratio of the length and diameter of the narrow bore 30b may be between about 5:1 to about 20:1.

[0032] Even though, capacitive plasma is generated in the exemplary Other forms of plasma, such as inductive plasma or plasma from remote plasma source, may be contemplated.

[0033] In one embodiment, one or more reaction enhancement agents may .be introduced to the inner volume 28 to assist plasma generation. Exemplary reaction enhancement agents may be H_2, Ar, He, Xe, Ne, CN, NH^3, or combinations thereof.

[0034] In one embodiment, the processing chamber 1 is configured to form one or more metal nitride films on the substrates 14 from a nitrogen source provided by the first gas source 34 and one or more metal precursors from a second gas source 36. In one embodiment, the second gas source 36 is connected to a second passage 32 formed in the first electrode 22. The second passage 32 has a plurality of openings 32a evenly distributed across a surface area of the first electrode 22 corresponding to the susceptor 12. In another embodiment, the second gas source 36 is connected directly or through a distribution assembly to the processing volume 18.

[0035] During process, a nitrogen source, such as a nitrogen gas, flows into the inner volume 28 of the gas distribution assembly 20, where the nitrogen source is dissociated when a plasma of the nitrogen gas is ignited by the RF power applied between the first and second electrodes 22, 26. The free nitrogen radical (nitrogen atoms) then flow through the first passages 30 to the processing volume 18. At the same time, metal precursors, in forms of chlorides or metal organic compounds, flows from the second gas source 36 to the processing volume 18. The substrate 14 and/or the processing volume 18 is heated to a temperature allowing the nitrogen

radical to react with the metal precursors and form one or more nitride films on the substrate 14.

[0036] In the process described above, ammonia is replaced by nitrogen radicals from a plasma from a nitrogen gas, thus reducing the temperature required for the metal nitride film formation since the highest processing temperature when using ammonia as nitrogen source is the temperature for heating ammonia and cracking ammonia to obtain free nitrogen atoms. Additionally, cost of ownership is also reduced because nitrogen gas is much cheaper than ammonia.

[0037] Embodiments of the present invention replace traditional thermal activated source with active source from a plasma and are particular advantageous in forming compound films by epitaxial growth. Particularly, embodiments of the present invention are advantageous in controlling properties of a compound epitaxial film, such as crystalline quality, growth rate, surface morphology, and carrier concentration.

[0038] More particularly, in the application of forming nitride film by MOCVD, embodiments of the present invention enable growth of high quality group-Ill metal nitrides. There are several growth challenges that make it difficult to produce high quality single crystal group-Ill metal -nitrides films by conventional MOCVD.

[0039] Of group-Ill metal nitrides, InN is difficult to grow due to its high equilibrium nitrogen vapor pressure. The high equilibrium vapor pressure of InN limits the deposition temperature to less than 650 C to prevent film decomposition. The source materials typically used in MOCVD growth of InN are TMIn (tri-methyl-indium) and ammonia. In conventional MOCVD, the growth temperature is usually used as controlling parameter for controlling film properties such as crystalline quality, growth rate, surface morphology and carrier concentration. Because InN's high equilibrium vapor pressure, there is a narrow temperature window (400 ^{0}C - 650 ^{0}C) for successful growth of InN by traditional MOCVD.

[0040] At these lower deposition temperatures, the extent of ammonia decomposition is very low, less than 0.1% at 500 ^{0}C and ~ 3% at 900^{0}C. Due to this lack of reactive nitrogen, indium droplets can form on the surface, therefore the inlet N source and In source ratio must be kept sufficiently high (~50,000) to avoid formation of indium droplets. Embodiment of the present invention can provide active nitrogen from a plasma formed within a gas distribution assembly and form quality InN film with a much smaller ratio of N source and In source, therefore, reducing cost.

[0041] Additionally, in traditional MOCVD, the extent of decomposition of ammonia, however, significantly increases the H_2 partial pressure, which has been shown to reduce the InN growth rate. Embodiments of the present invention can replace ammonia with nitrogen gas as nitrogen source, therefore, eliminating or reducing hydrogen and achieve higher InN growth rate.

[0042] Another film, $In_xGa_{1-x}N$ (x is usually between about 0.02 to about 0.3), which usually is comprised in one of the layers in LED devices, is fairly difficult to form using conventional MOCVD using thermal activated nitrogen source. There are several growth challenges that must be overcome for successful growth of $In_xGa_{1-x}N$ alloys.

[0043] One challenge is that phase separation occurs in the $In_xGa_{1-x}N$ alloy due to an 11% lattice mismatch between InN and GaN. It was proven that single phase metastable $In_xGa_{1-x}N$ can be grown over the entire compositional range by MBE (molecular beam epitaxy) when a low temperature is used. Another challenge is the vapor pressure difference between InN and GaN that affects high quality growth of $In_xGa_{1-x}N$ alloys. At lower deposition temperature indium incorporation can be increased. The distribution coefficient of Indium between the vapor and solid phases is considerably greater than unity at 800 ^{0}C because of the large difference in decomposition pressure at elevated temperature along with near equilibrium conditions at the growth interface at this higher temperature. At the lower temperature of 500 ^{0}C the distribution coefficient is close to unity suggesting non-

equilibrium (reaction limited) conditions are expected. It is also evident that at 800 ^{0}C (typical growth T for traditional InGaN MQWs at LEDs production), control of the composition becomes difficult for intermediate compositions given the rapid change in solid composition with that in the vapor. Additionally, choosing the optimal N/group-lll metal inlet ratio is directly affected by the specified deposition temperature. In traditional MOCVD, ammonia decomposition efficiency determines the actual N/group-lll metal ratio. However, it is very difficult to obtain the exact NH_3 decomposition efficiency since the value relies heavily on the reactor design as well as temperature. When the deposition temperature is low ($\leq$ 600 ^{0}C) the inlet N/group-lll metal ratio must be high enough to maintain sufficient levels of active nitrogen and avoid In droplet formation. As the temperature is increased above 650^{0}C the N/group-lll metal ratio must be appropriately decreased so the excess hydrogen partial pressure doesn't inhibit In incorporation into the film.

[0044] Embodiments of the present invention improve formation of $In_xGa_{1-x}N$ by allowing reaction at lower temperature using activated nitrogen from a plasma and allow easy control of N/group-lll metal ratio by avoiding ammonia.

[0045] In one embodiment, the gas distribution assembly 20 may be connected to a source of cleaning agent and configured to generate a plasma of the cleaning agent and provide species from the plasma for performing a downstream cleaning, such as cleaning the passages 30, the chamber walls, substrate supporting surfaces, and the exhaust. In one embodiment, the cleaning agent comprises chlorine gas.

[0046] Figure 2 is a schematic sectional side view of a MOCVD chamber 200 in accordance with one embodiment of the present invention. The MOCVD chamber 200 is configured to form one or more Group-III metal nitride film from nitrogen radicals and metal organic precursors by a MOCVD process.

[0047] The MOCVD chamber 200 comprises a chamber body 210, and a susceptor 212 and a gas distribution assembly 220 disposed in the chamber body

210. The gas distribution assembly 220 is similar to the gas distribution assembly 20 of Figure 1.

[0048] The susceptor 212 is configured to support one or more substrates 214 to expose the one or more substrates 214 to precursors in a processing volume 218 to be processed. In one embodiment, the susceptor 212 comprises a heater 216 configured to heat the one or more substrates 214 to a temperature required by the process being performed. In one embodiment, the susceptor 212 may be configured to rotate the one or more substrate 214 during processing.

[0049] The gas distribution assembly 220 comprises a first electrode 222, a second electrode 226 and an insulator 224 disposed between the first electrode 222 and the second electrode 226. The first electrode 222, insulator 224 and the second electrode 226 defines an inner volume 228. In one embodiment, the first electrode 222 is coupled to a RF (radio frequency) ground, the second electrode 226 is coupled to a RF power source 240, and the insulator 224 electrically insulates the first electrode 226 from the second electrode 226.

[0050] A first gas source 234 is connected the inner volume 228 to provide a nitrogen containing gas to the inner volume 228. A capacitive plasma can be generated in the inner volume 228 when an RF power is applied to the second electrode 226.

[0051] The first electrode 222 is disposed between the second electrode 226 and the susceptor 212 shielding the susceptor 212 and the one or more substrates 214 from the RF field of the second electrode 226 during plasma generation.

[0052] In one embodiment, the gas distribution assembly 220 may be secured by a clamp 227 made from insolating material, such as ceramics. In one embodiment, the clamp 227 is made of aluminum oxide (Al_2O_3).

[0053] In one embodiment, the second electrode 226 may be a planar disk formed from a conductive material, such as metal or alloys. In one embodiment, the

second electrode 226 is formed from stainless steel. The insulator 224 may be formed from a ceramic, such as aluminum nitride (AIxNy).

[0054] The first electrode 222 may be formed conductive materials, such as aluminum, and or stainless steel. In one embodiment, the first electrode 222 may formed from several disk shaped material joined together.

[0055] The first electrode 222 has a plurality of first passages 230 formed therethrough. Each passage 230 connects the inner volume 228 to the processing volume 218. In one embodiment, the plurality of first passages 230 are evenly distributed across a surface area of the first electrode 222 corresponding to a surface area of the susceptor 212.

[0056] The MOCVD chamber 200 further comprises a vacuum pump 238 configured to pump out the processing volume 218 and obtain a desired pressure level in the processing volume 218. In one embodiment, the MOCVD chamber 200 comprises a pumping ring 235 disposed in the processing volume 218. The pumping ring 235 defines a plenum 239 connected to the processing volume 218 via a plurality of holes 237 evenly distributed around the susceptor 212. The vacuum pump 238 is in fluid communication with the plenum 239. The pumping ring 235 allows even pumping in the processing volume 218. During processing, the vacuum pump 238 provides a negative pressure in the processing volume 218 relative to the inner volume 228 of the gas distribution assembly 220, thus, allowing the species in the inner volume 228 to flow to the processing volume 218.

[0057] The gas distribution assembly 220 is configured to generate a plasma within to disassociate the nitrogen source, and provide nitrogen radials in the plasma to the processing volume 218 while shielding the RF field of the plasma from the processing volume 218.

[0058] In one embodiment, shielding the electric filed of the plasma may be achieved by providing one or more baffle features in each passage 230 which connects the inner volume 228 and the processing volume 218.

[0059] The spacing 229 between the first electrode 222 and the second electrode 226 may be between about 3mm to abut 30mm. The spacing 229 may be adjusted to improve efficiency of RF power during plasma generation.

[0060] Figure 3A is a partial sectional side view of the first electrode 222. The first electrode 222 has a plurality of first passages 230 configured to flow radials from the inner volume 228 to the external. The plurality of first passages 230 may be evenly distributed over the first electrode 222. In one embodiment, as shown in Figure 3B, the plurality of first passages 230 are arranged in a hexagon pattern.

[0061] Referring back to Figure 3A, the passage 230 comprises a cone shaped channel 230a connected to a narrow bore 230b. The cone shaped channel 230a has a wide opening towards the inner volume 228 and a narrow opening connected to the narrow bore 230b. An aspect ratio of the narrow bore 230b is adjusted to retain the plasma within the inner volume 228. In one embodiment, the cone shaped channel 230a may have an angle of about 22°. In one embodiment, the cone shaped channel 230a may have a length of about 8mm.

[0062] The narrow bore 230b is configured to provide a baffle to retain the plasma within. The diameter, length, or aspect ratio of the length and diameter may be affected by pressure, flow rate, species in the plasma, or other effectors. In one embodiment, an aspect ratio of the length and diameter of the narrow bore 230b may be between about 5:1 to about 20:1. In one embodiment, the narrow bore 230b may have a diameter between about 0.5mm to about 12mm. In one embodiment, the narrow bore 230b may have a length of about 12mm.

[0063] The first electrode 222 also has a cooling channel 245 formed therein. The cooling channel 245 may be connected to a cooling fluid exchanging system 244 (shown in Figure 2) and allow cooling fluid circulating in the first electrode 222. In one embodiment, the cooling fluid exchange system 244 may also connected to cooling channels 211 in the chamber body configured to cool the chamber body. In one embodiment, water is used as the cooling fluid. The first electrode 222 may be maintained at a temperature of about 100° C during processing. In one

embodiment, the cooling channel may be formed close to the cone shaped channels 230a. In one embodiment, the cooling channel 245 may have a triangular sectional shape. Figure 3C showing one embodiment of an arrangement of the cooling channel 245.

[0064] Referring back to Figure 3A, the first electrode 222 has a second passage 232 formed therein to provide connection between a second gas source 236 (shown in Figure 2) and the processing volume 218. The second passage 232 has a plurality of openings 232a evenly distributed across a surface area of the first electrode 222 corresponding to the susceptor 212. The height of the second passage 232 and the diameter of the openings 232a may be adjusted to reduce non-uniformity in gas distribution caused by pressure fluctuation the second passage 232. In one embodiment, the second passage 232 may have a height of about 6mm and the second opening 232a has a length of about 4mm. Figure 3D illustrates one embodiment of the second passage 232.

[0065] The arrangement shown in Figures 3A-3D has a ratio of the narrow bore 230b for the first gas source and the opening 232a for the second gas source at 2:1. However, other arrangements are also contemplated by embodiments of the present invention.

[0066] As shown in Figure 3A, the first electrode 222 may be formed from four disks 222a, 222b, 222c, and 222d to enable formation of channels and passages. The cone shaped channels 230a and the cooling channels 245 are formed in the disk 222a. The disk 222b has a plurality of through holes providing a length portion of the narrow bores 230b formed therein. Disks 222a and 222b may be joined together by brazing. Disk 222c has a plurality of through holes providing a length portion of the narrow bores 230b and slits for the second passage 232. Disk 222d has through holes for the openings 232a and a length portion of the narrow bores 230b.

[0067] In one embodiment, disks 222a, 222b, 222c may be formed from aluminum and joined together by brazing, and disk 222d may be formed from stainless steel and joined with disk 222c by explosion.

[0068] In one embodiment, the first electrode 222 may be formed from an electrically conductive metal, a metal ceramic compound, ceramic with embedded electrode, or layer stack of metal ceramics.

[0069] In one embodiment, the second gas source 236 is configured to provide a metal organic compound. In one embodiment, the second gas source 236 is a gallium source, such as trimethylgallium (TMG) or triethylgallium (TEG) for forming gallium nitride film.

[0070] During a MOCVD deposition of a gallium nitride film using the MOCVD chamber 200, a nitrogen source, such as a nitrogen gas, flows into the inner volume 228 of the gas distribution assembly 220, where the nitrogen source is dissociated when a plasma of the nitrogen gas is ignited by the RF power applied between the first and second electrodes 222, 226. The free nitrogen radical (nitrogen atoms) then flow through the first passages 230 to the processing volume 218. At the same time, a gallium source, such as TMG or TEG, is flown from the second gas source 236 to the processing volume 218. The substrate 214 and/or the processing volume 218 is heated to a temperature allowing the nitrogen radical to react with the metal precursors and form one or more nitride films on the substrate 214. In one embodiment, the substrate 214 is heated at a temperature of about 700^{0}C.

[0071] Figure 4 is a schematic view of an HVPE apparatus 100 according to one embodiment. The apparatus 100 comprises a chamber 102 enclosed by a lid 104.

[0072] Processing gas from a first gas source 110 is delivered to the chamber 102 through a gas distribution assembly 106 disposed in an upper portion of the chamber 102. In one embodiment, the gas source 110 may comprise nitrogen gas, or a nitrogen containing compound. The gas distribution assembly 106 and the

chamber walls 108 define a processing volume 107. A susceptor 114 is disposed in the processing volume 107 and configured to support one or more substrates 116.

[0073] The gas distribution assembly 106 is configured to generate a plasma from a gas source and to deliver radicals from the plasma to the processing volume 107 without exposing the processing volume 107 to the electric field of the plasma.

[0074] The gas distribution assembly 106 comprises a first electrode 161, a second electrode 163, and an insulator 162 disposed between the first electrode 161 and the second electrode 163.

[0075] The gas distribution assembly 106 comprises a first electrode 161, a second electrode 163 and an insulator 162 disposed between the first electrode 161 and the second electrode 163. The first electrode 161, insulator 162 and the second electrode 163 defines an inner volume 164. In one embodiment, the first electrode 161 is coupled to a RF (radio frequency) ground, the second electrode 163 is coupled to a RF power source 105, and the insulator 24 electrically insulates the first electrode 161 from the second electrode 163.

[0076] A first gas source 110 is connected the inner volume 164 to provide one or more reactive gases to the inner volume 164. A capacitive plasma can be generated in the inner volume 164 when an RF power is applied to the second electrode 163.

[0077] The first electrode 161 is disposed between the second electrode 163 and the susceptor 114 shielding the susceptor 114 and the one or more substrates 116 from the RF field of the second electrode 163 during plasma generation.

[0078] As shown in Figure 5, the first electrode 161 has a plurality of first passages 165 formed therethrough. Each passage 165 connects the inner volume 164 to the processing volume 107. In one embodiment, each passage 165 comprises a cone shaped channel 173 connected to a narrow bore 174. In one embodiment, an aspect ratio of the length and diameter of the narrow bore 174 may be between about 5:1 to about 20:1. The first electrode 161 also has cooling

channels 166 formed therein. In one embodiment, the first electrode 161 may be formed from two disks 171, 172 joint together.

[0079] In one embodiment, an inert gas such as helium or diatomic nitrogen may be introduced as well either through the gas distribution assembly 106 or through the walls 108 of the chamber 102.

[0080] The apparatus 100 further comprises a second gas source 118 comprising precursors to react with the nitrogen source from the first gas source 110. The second gas source 118 may have a chamber 132 configured to generate precursor for processing in the processing chamber 102. The second gas source 118 is configured to provide precursors containing one or more Group-III metals disposed in a boat 117. In one embodiment, second gas source 118 comprises a gallium precursor and an aluminum precursor. In one embodiment, the precursor comprises gallium present in the second gas source 118 in liquid form. In another embodiment, the precursor comprises aluminum present in the second gas source 118 in solid form. In one embodiment, the aluminum precursor may be in solid, powder form.

[0081] In one embodiment, the second gas source 118 is connected to a reactive gas source 119. The precursor may be delivered to the chamber 102 in forms of compound gas generated by flowing a reactive gas from the reactive gas source 119 over and/or through the precursor in the second gas source 118. In one embodiment, the reactive gas may comprise a chlorine containing gas such as diatomic chlorine. The chlorine containing gas may react with the precursor source such as gallium or aluminum to form a chloride, which is then delivered to the processing chamber 102.

[0082] In order to increase the effectiveness of the chlorine containing gas to react with the precursor, the chlorine containing gas may snake through the boat 117 in the chamber 132 and be heated with the resistive heater 120. By increasing the residence time that the chlorine containing gas is snaked through the chamber 132, the temperature of the chlorine containing gas may be controlled. By

increasing the temperature of the chlorine containing gas, the chlorine may react with the precursor faster. In other words, the temperature is a catalyst to the reaction between the chlorine and the precursor.

[0083] In order to increase the reactiveness of the precursor, the precursor may be heated by a resistive heater 120 within the chamber 132. For example, in one embodiment, the gallium precursor may be heated to a temperature of between about 750 degrees Celsius to about 850 degrees Celsius. The chloride reaction product may then be delivered to the chamber 102. The reactive chloride product first enters a tube 122 where it evenly distributes within the tube 122. The tube 122 is connected to another tube 124. The chloride reaction product enters the second tube 124 after it has been evenly distributed within the first tube 122. The chloride reaction product then enters into the chamber 102 where the chloride reaction product mixes with the nitrogen radials from the gas distribution assembly 106 and forms a nitride layer on the substrate 116 that is disposed on a susceptor 114.

[0084] In one embodiment, the susceptor 114 may comprise silicon carbide. The nitride layer may comprise gallium nitride or aluminum nitride for example. The other reaction product, such as nitrogen and chlorine, are exhausted through an exhaust 126.

[0085] The chamber 102 may have a thermal gradient that can lead to a buoyancy effect. For example, the nitrogen radicals are introduced through the gas distribution assembly 106 at a temperature between about 100 degrees Celsius. The chamber walls 108 may have a temperature of about 600 degrees Celsius to about 700 degrees Celsius. The susceptor 114 may have a temperature of about 1050 to about 1150 degrees Celsius. Thus, the temperature difference within the chamber 102 may permit the gas to rise within the chamber 102 as it is heated and then fall as it cools. The raising and falling of the gas may cause the nitrogen radicals and the chloride gas to mix. Additionally, the buoyancy effect will reduce the amount of gallium nitride or aluminum nitride that deposits on the walls 108 because of the mixing.

[0086] The heating of the processing chamber 102 is accomplished by heating the susceptor 114 with a lamp module 128 that is disposed below the susceptor 114. During deposition, the lamp module 128 is the main source of heat for the processing chamber 102. While shown and described as a lamp module 128, it is to be understood that other heating sources may be used. Additional heating of the processing chamber 102 may be accomplished by use of a heater 130 embedded within the walls 108 of the chamber 102. The heater 130 embedded in the walls 108 may provide little if any heat during the deposition process.

[0087] After the deposition process, the substrate 116 is normally taken out of the processing chamber 102. The lamp module 128 is turned off. Within the heat from the lamp module 128, the chamber 102 may rapidly cool. The gallium nitride or aluminum nitride that may have deposited on the walls 108 may have a different coefficient of thermal expansion than the walls 108 themselves. Thus, the gallium nitride or the aluminum nitride may flake off due to thermal expansion. To prevent undesired flaking, the heater 130 embedded within the chamber walls 108 may be turned on to control the thermal expansion and maintain the chamber 102 at the desired chamber temperature. The control of the heater 130 may again be based upon real time feedback from the thermocouple. Once the lamp module 128 is turned off, the heater 130 may be turned on or up to maintain the temperature of the chamber 102 at the desired temperature so that gallium nitride or aluminum nitride may not flake off and contaminate the substrate or land on the susceptor 114 and create an uneven susceptor 114 surface. By maintaining the chamber walls 108 at an elevated temperature, the chlorine will be more effective in cleaning the depositions from the chamber walls 108.

[0088] While the nitrogen containing gas is discussed as being introduced through the gas distribution assembly 106 and the precursor delivered in the area corresponding to the middle of the chamber 102, it is to be understood that the gas introduced locations may be adjusted as needed.

[0089] Even though, metal nitride film formation is discussed with embodiments of the present invention, other processes where radicals are required can also be performed by apparatus and method of the present invention.

[0090] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is Claimed is:

1. A chamber for processing one or more substrates, comprising:

a chamber body defining a processing volume;

a susceptor disposed in the processing volume and configured to support the one or more substrates;

a gas distribution assembly disposed over the susceptor, wherein the gas distribution assembly is configured to generate a plasma and provide one or more radical species from the plasma to the processing volume while shielding electrical field of the plasma from the processing volume;

a RF (radial frequency) power source coupled to the gas distribution assembly;

a first reactant gas source coupled to the gas distribution assembly; and

a second react gas source in fluid communication with the processing volume.

2. The chamber of claim 1, wherein the gas distribution assembly comprises:

a first electrode having a plurality of first passages connecting a first side of the first electrode and a second side of the electrode, wherein the first side of the first electrode faces the processing volume, and each first passage has a narrow opening on the first side and a wide opening on the second side;

a second electrode substantially parallel to the first electrode, wherein the second side of the first electrode faces the second electrode, a plasma generating volume is defined between the first and second electrodes, and the first reactant gas source is connected to an inlet of the plasma generating volume; and

an insulator disposed between the first and second electrodes near perimeters of the first and second electrodes and providing electrical insulation between the first and second electrodes, wherein the second electrode is coupled to the RF power source and the first electrode is grounded.

3. The chamber of claim 2, wherein each first passage is defined by a cone opening to the first side of the first electrode connected to a bore opening to the second side of the first electrode.

4. The chamber of claim 3, wherein a ratio of the depth and the diameter of the bore is between about 5:1 to about 20:1.

5. The chamber of claim 3, wherein the first electrode has a plurality of second passages, each second passage is defined by a bore opening to the second side of the first electrode and connected to an inner gas channel distributed within the first electrode, and the inner gas channel is connected to the second reactant gas source.

6. The chamber of claim 2, further comprises a gas inlet ring disposed in the processing volume between the susceptor and the gas distribution assembly, wherein the gas inlet ring is connected to the second reactant gas source and has a plurality of openings in fluid communication with the processing volume.

7. The chamber of claim 6, wherein the second reactant gas source comprises:

a reactive product boat;

a first reactive product source disposed in the reactive product boat;

a second reactive product source coupled to the reactive product boat; and

a heating element coupled to the reactive product boat.

8. A gas distribution assembly for providing radicals of a reactant gas to a processing region, comprising:

a first electrode having a plurality of first passages connecting a first side of the first electrode and a second side of the electrode, wherein the first side of the first electrode is configured to face the processing region, and each first passage has a narrow opening on the first side and a wide opening on the second side;

a second electrode substantially parallel to the first electrode, wherein the second side of the first electrode faces the second electrode, and a plasma generating volume is defined between the first and second electrodes; and

an insulator disposed between the first and second electrodes near perimeters of the first and second electrodes and providing electrical insulation between the first and second electrodes.

9. The gas distribution assembly of claim 8, wherein the first electrode is electrically coupled to a RF (radio frequency) ground, the second electrode is electrically coupled to a RF power source, and the plurality of first passages are configured to retain RF field within the gas distribution assembly.

10. The gas distribution assembly of claim 9, wherein each first passage is defined by a cone opening to the first side of the first electrode connected to a bore opening to the second side of the first electrode.

11. The gas distribution assembly of claim 10, wherein a ratio of the depth and the diameter of the bore is between about 5:1 to about 20:1.

12. A method for processing one or more substrates, comprising:

disposing the one or more substrates on a susceptor disposed in a processing volume of a processing chamber, wherein the processing chamber comprises a gas distribution assembly disposed over the susceptor, and the gas distribution assembly has a plasma generating volume;

flowing a first reactive gas to the plasma generating volume of the gas distribution chamber;

igniting a plasma within the plasma generating volume to generate radicals of the first reactive gas;

introducing the radials of the first reactive gas to the processing volume while shielding the plasma from the processing volume;

flowing a second reactive gas to the processing volume; and

forming a film over the one or more substrate, wherein the film is a reactive product of the first reactive gas and the second reactive gas.

13. The method of claim 12, wherein the gas distribution assembly comprises a first electrode facing the susceptor and a second electrode disposed over the first electrode, the plasma generating volume is defined between the first and second electrodes, the first electrode comprises a plurality of first passages connecting the plasma generating volume to the processing volume, and igniting the plasma comprises applying a RF (radio frequency) power source to the second electrode, and electrically grounding the first electrode.

14. The method of claim 13, wherein the first reactive gas is a nitrogen source and the second reactive gas comprises a group-III metal, and flowing the second reactive gas to the processing volume comprises:

heating the second reactive gas remotely from the processing chamber; and

introducing the second reactive gas into the processing volume through a gas inlet ring disposed in the processing volume between the gas distribution assembly and the susceptor.

15. A method for cleaning a processing chamber, comprising:

flowing a cleaning gas to a plasma generating volume of the gas distribution assembly of the processing chamber, wherein the gas distribution assembly comprises:

a first electrode having a plurality of first passages connecting a first side of the first electrode and a second side of the electrode, wherein the first side of the first electrode is configured to face a processing volume of the processing chamber, and each first passage has a narrow opening on the first side and a wide opening on the second side;

a second electrode substantially parallel to the first electrode, wherein the second side of the first electrode faces the second electrode, and the

plasma generating volume is defined between the first and second electrodes; and

an insulator disposed between the first and second electrodes near perimeters of the first and second electrodes and providing electrical insulation between the first and second electrodes;

igniting a plasma within the plasma generating volume to generate radicals of the cleaning gas; and

introducing the radials of the cleaning gas to the processing volume while shielding the plasma from the processing volume of the processing chamber.

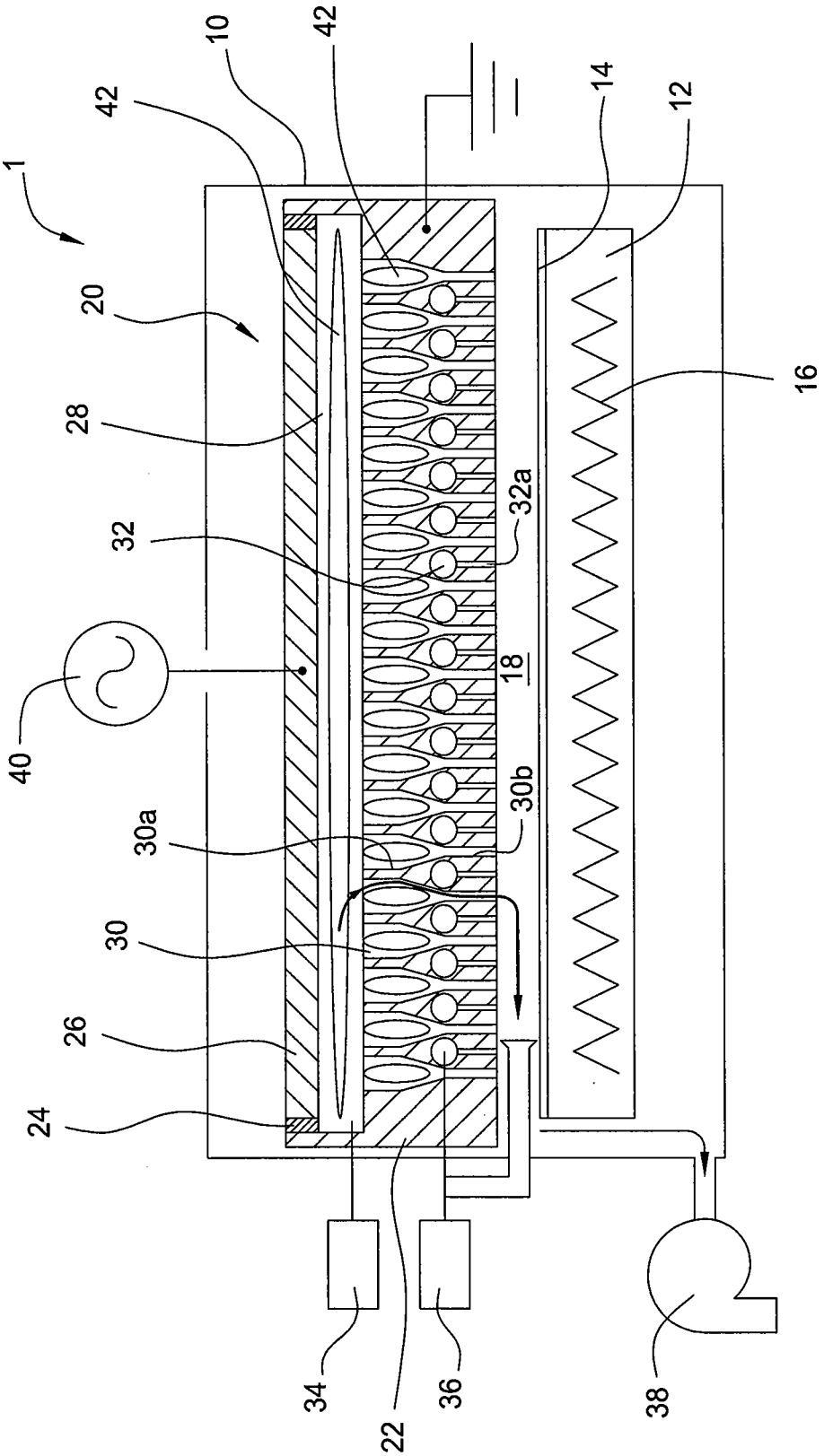

FIG. 1

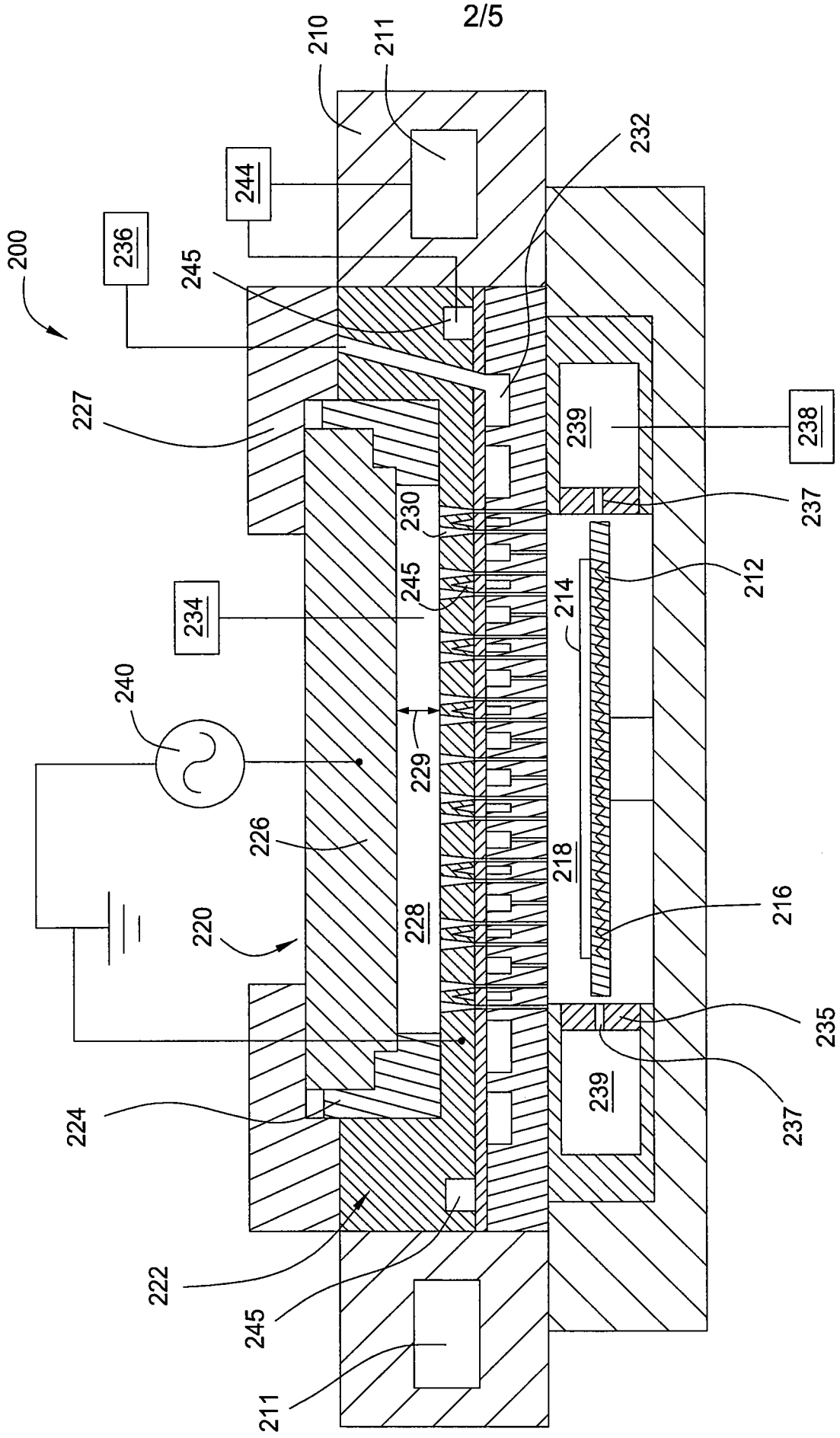
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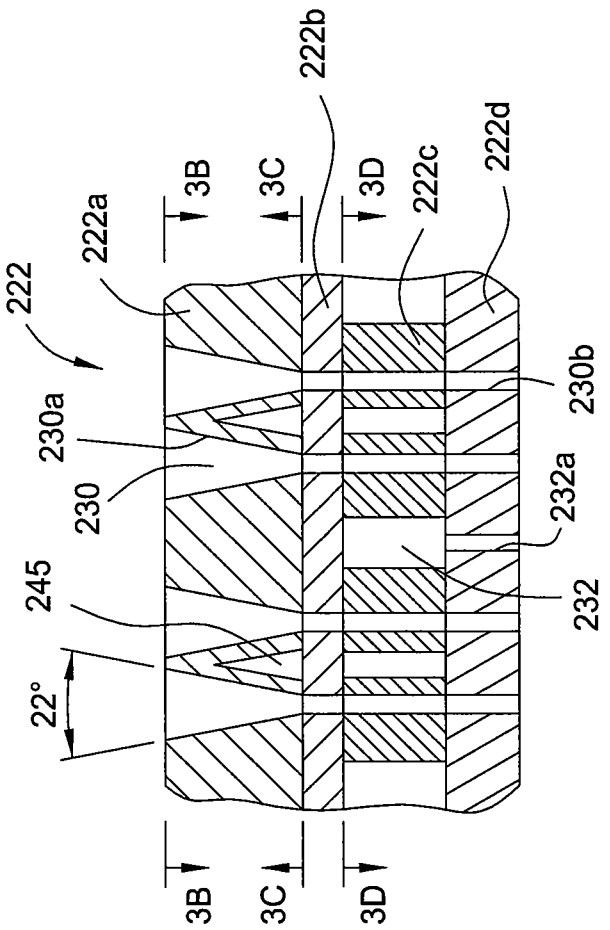
FIG. 2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3C
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22°

FIG. 3A

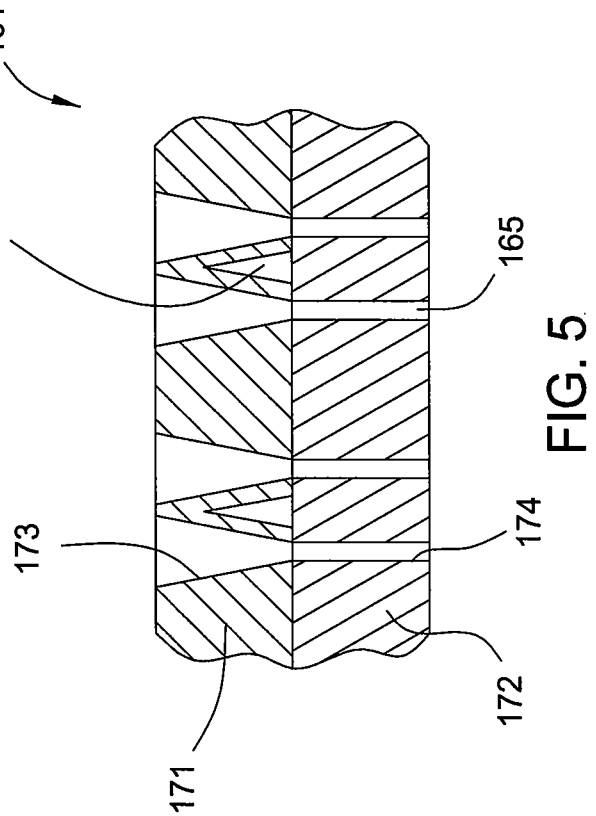
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FIG. 5

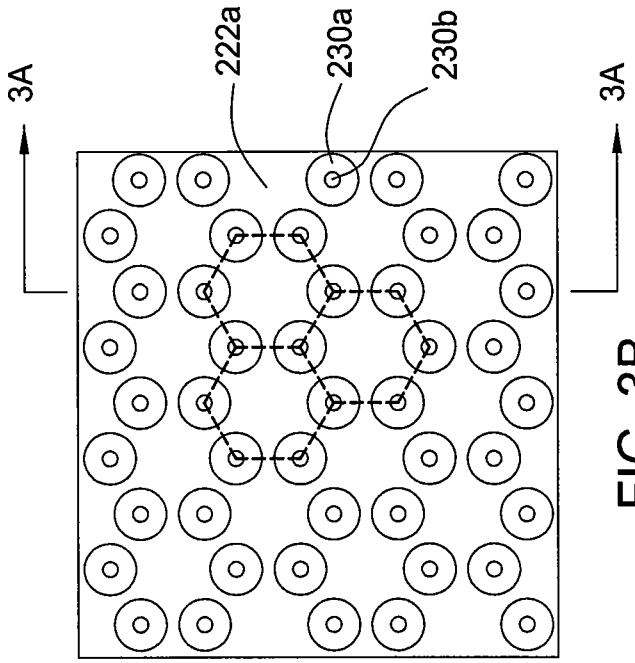


FIG. 3B

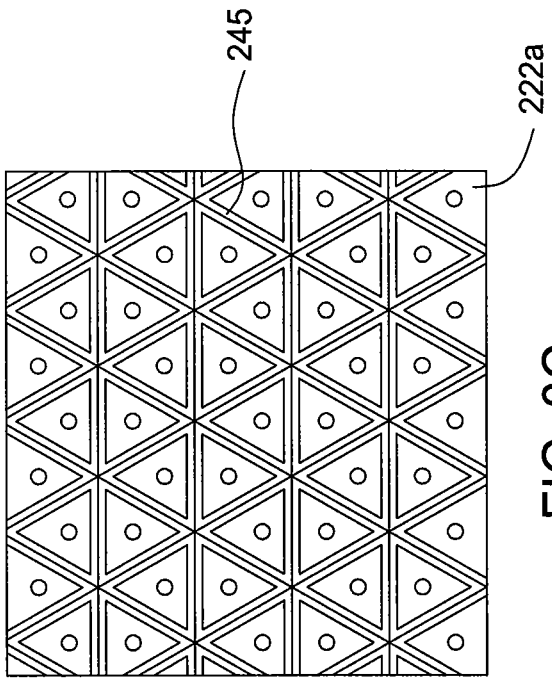


FIG. 3C

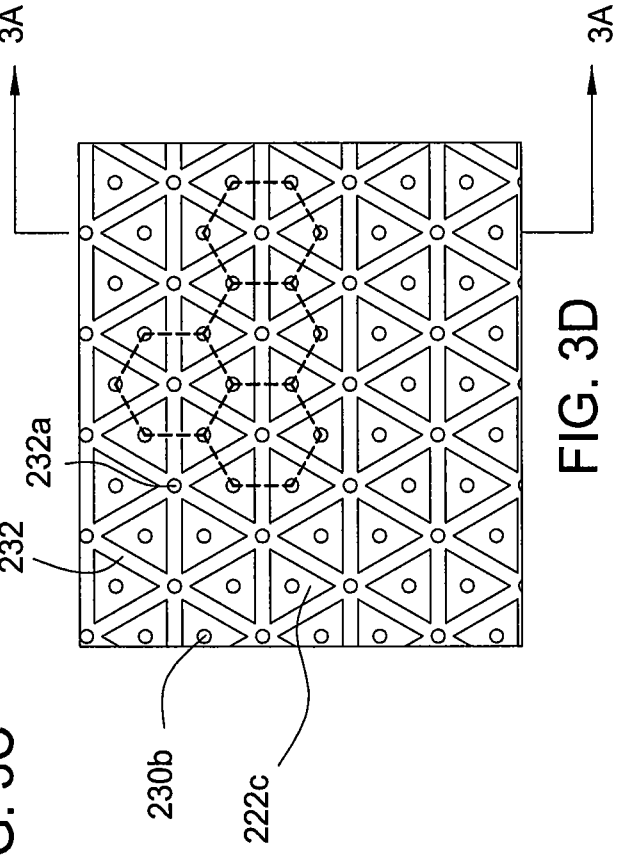
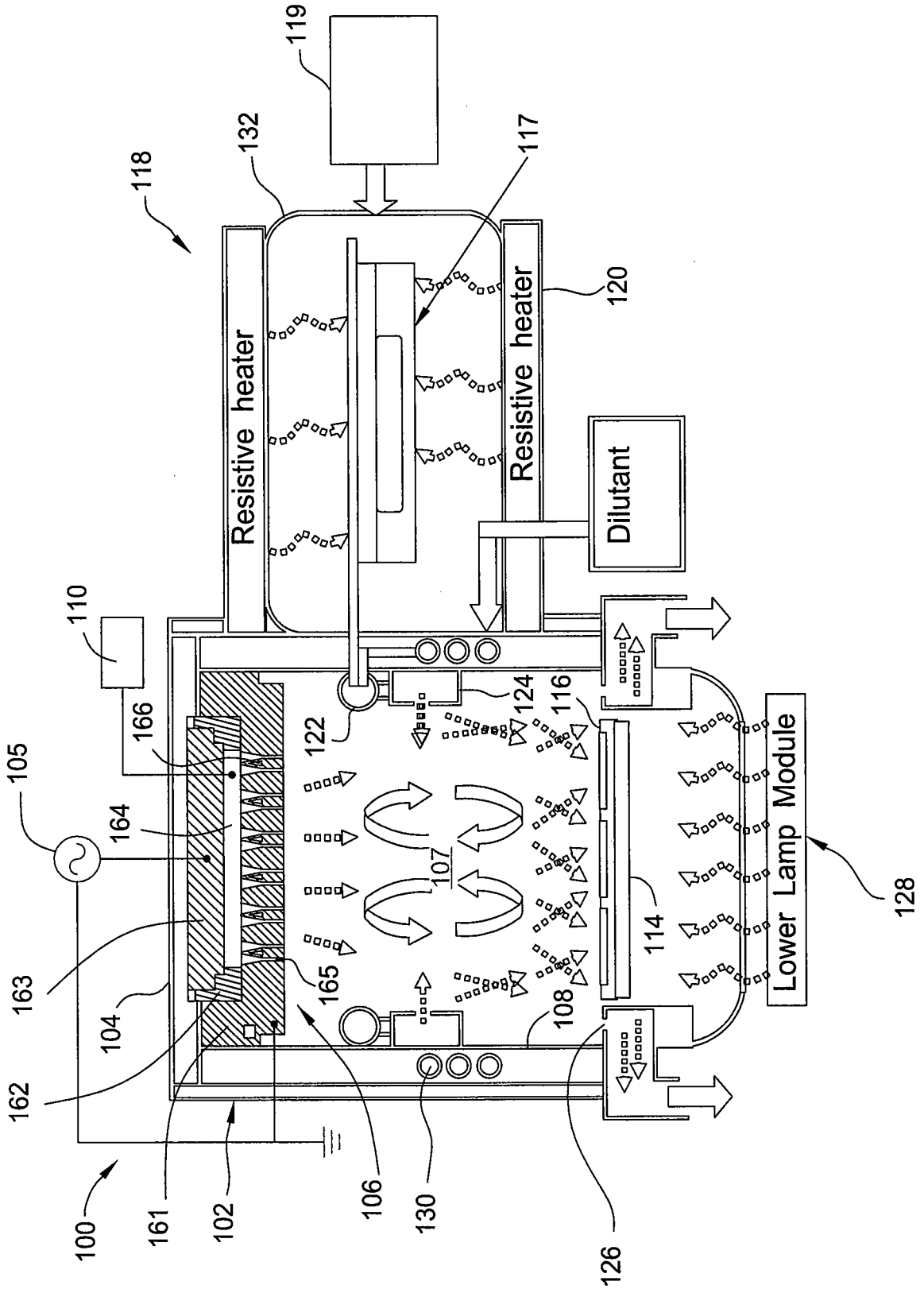


FIG. 3D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132
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117
Resistive heater
120
Resistive heater
Dilutant
110
166
105
164
163
104
162
165
122
124
116
107
114
108
Lower Lamp Module
128
100
161
102
106
130
126

FIG. 4