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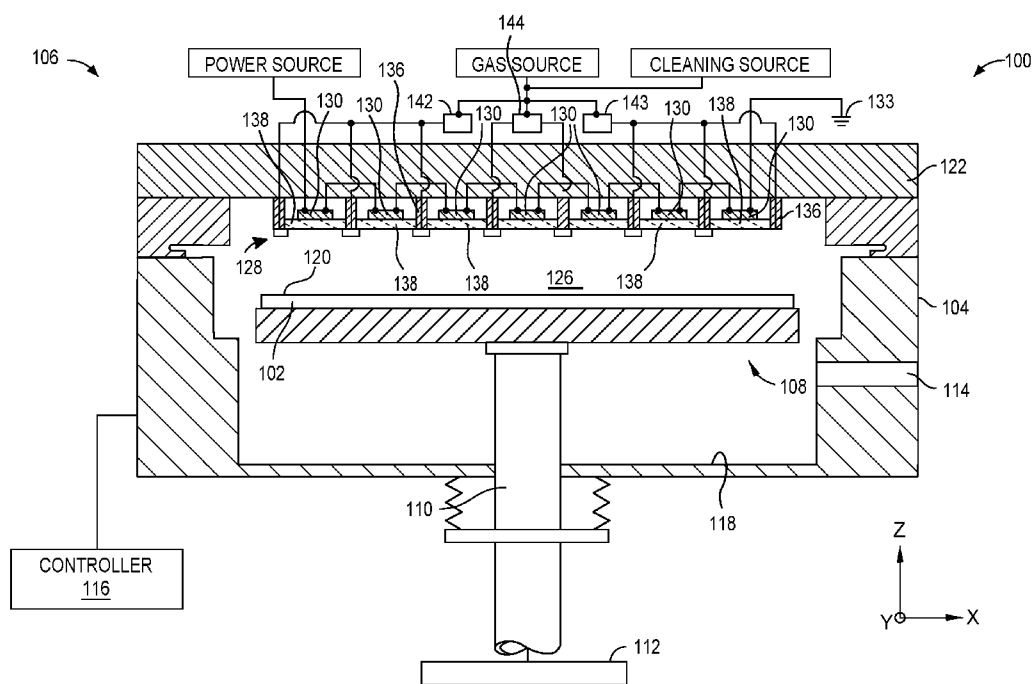


FIG. 1

(57) Abstract: The present disclosure is directed to an antenna array. The antenna array includes a plurality of inductive couplers, comprising a plurality of antennas disposed over a dielectric window and an electrode disposed under the antenna array. The plurality of dielectric windows may be coupled to a plurality of interface members comprising a plurality of gas ports. A controller of a process system stores instructions that, when executed by a processor, causes the system to process a substrate within a processing chamber by flowing a process gas through a plurality of interface members having a gas port into a processing region, forming a plasma using a plurality of inductive couplers, and depositing a film on the substrate. The processing chamber further includes a plurality of sensors to measure a deposition rate, a power supply, a temperature, and a gas flow rate; calculate a deposition rate on the substrate; and adjust a processing chamber parameter.

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ANTENNA ARRAYS WITH ELECTRODE FOR HIGH DENSITY PLASMA ENHANCED PROCESS CHAMBER

BACKGROUND

Field

[0001] Embodiments of the present disclosure generally relate to process chambers, such as high-density plasma (HDP) chambers. More particularly, embodiments of the present disclosure relate to symmetric antenna arrays for HDP chambers.

Description of the Related Art

[0002] In the manufacture of solar panels or flat panel displays, many processes are employed to deposit thin films on substrates, such as semiconductor substrates, solar panel substrates, and liquid crystal display (LCD) and/or organic light emitting diode (OLED) substrates, to form electronic devices thereon. The deposition is generally accomplished by introducing a precursor gas into a chamber having a substrate disposed on a temperature controlled substrate support. The precursor gas is typically directed through a gas distribution assembly disposed above the substrate support. The precursor gas in the chamber is energized (e.g., excited) into a plasma by applying a single or array of radio frequency (RF) antennas inductively coupled to the precursor gas to form the plasma. The excited gas reacts to form a layer of material on a surface of the substrate that is positioned on the temperature controlled substrate support.

[0003] The size of the substrates for forming the electronic devices exceeds 1 square meter in surface area. Uniformity in film thickness across these substrates is difficult to achieve. Film thickness uniformity becomes even more difficult as the substrate sizes increase. To provide uniform thicknesses, gases can be provided to the process region in a plurality of gas distribution zones. Each of the gas distribution zones include plenums that are used to control gas distribution and plasma formation. Uniformity of plasma production, however, continues to be a challenge as substrate sizes continue to increase.

[0004] Accordingly, what is needed in the art is a method and apparatus for improved thickness uniformity across large substrates.

SUMMARY

[0005] Embodiments of the present disclosure include a method, apparatus, and system distributing plasma.

[0006] In one embodiment, an antenna array is disclosed. The antenna array includes a plurality of inductive couplers, comprising a plurality of antennas disposed over a dielectric window and an electrode disposed under the antenna array.

[0007] In another embodiment, an antenna array is disclosed. The antenna array includes a plurality of dielectric windows, a plurality of inductive couplers, and an electrode disposed under the inductive couplers. The plurality of dielectric windows are coupled to a plurality of interface members comprising a plurality of gas ports. The plurality of inductive couplers include a plurality of antennas disposed over the plurality of dielectric windows.

[0008] In still other embodiments, a controller of a process system stores instructions that, when executed by a processor, causes the system to process a substrate within a processing chamber by flowing a process gas through a plurality of interface members having a gas port into a processing region, forming a plasma using a plurality of inductive couplers, and depositing a film on the substrate. The processing chamber further includes a plurality of sensors to measure a deposition rate, a power supply, a temperature, and a gas flow rate; calculate a deposition rate on the substrate; and adjust a processing chamber parameter. The process system includes an electrode disposed under the plurality of inductive couplers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, 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 exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

[0010] Figure 1 illustrates a cross sectional side view of a processing chamber, according to embodiments of the disclosure.

[0011] Figure 2A illustrates a schematic cross-sectional perspective view of a portion of an antenna array with an electrode disposed below a dielectric window, according to embodiments of the disclosure.

[0012] Figure 2B illustrates a schematic bottom view of a portion of the antenna array with an electrode disposed below the dielectric window, according to embodiments of the disclosure.

[0013] Figure 2C illustrates a schematic cross-sectional side view of a portion of the antenna array with an electrode disposed below the dielectric window, according to embodiments of the disclosure.

[0014] Figure 3 illustrates a top plan view of an antenna of an inductive coupler, according to embodiments of the disclosure.

[0015] Figure 4 illustrates a schematic perspective view of a portion an antenna sub-array of the antenna array, according to embodiments of the disclosure.

[0016] Figure 5A illustrates a schematic cross-sectional perspective view of a portion of an antenna array with an electrode disposed within a dielectric window, according to embodiments of the disclosure.

[0017] Figure 5B illustrates a schematic cross-sectional side view of a portion of the antenna array with an electrode disposed within the dielectric window, according to embodiments of the disclosure.

[0018] Figure 6A illustrates a schematic cross-sectional perspective view of a portion of an antenna array with an electrode disposed below a dielectric window, according to embodiments of the disclosure.

[0019] Figure 6B illustrates a schematic top view of a portion of the antenna array with an electrode disposed below the dielectric window, according to embodiments of the disclosure.

[0020] Figure 6C illustrates a schematic cross-sectional side view of a portion of the antenna array with an electrode disposed below the dielectric window, according to embodiments of the disclosure.

[0021] 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 and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0022] Embodiments of the present disclosure generally relate to process chambers, such as high-density plasma (HDP) chambers. More particularly, embodiments of the present disclosure relate to antenna arrays (e.g., symmetric antenna arrays) for HDP chambers.

[0023] Herein, a plurality of interface members are configured to flow gas therethrough and into a processing volume of a chamber in a number of independently controlled zones, in order to improve the uniformity of the processing of the surface of a substrate exposed to the gas in the processing zone. The processing zone is configured to allow processing gas(es) to be flowed thereinto and distributed to result in a relatively uniform flow rate, or in some cases tailored flow rate, of the gases into the processing volume. An inductive coupler, such as a radiofrequency (RF) antenna, is positioned proximate to the dielectric window, and the inductive coupler inductively couples energy through the dielectric window to strike and support a plasma in the processing volume. The flow of the process gas(es) in each zone is controlled to result in uniform or tailored gas flows to achieve desired process results on the substrate.

[0024] Embodiments of the disclosure include a high density plasma chemical vapor deposition (HDP CVD) processing chamber that is operable form one or more layers or films on a substrate. The processing chamber as disclosed herein is adapted to deliver energized species of a precursor gas that are generated in a plasma. The plasma may be generated by inductively coupling energy into a gas under vacuum. It is to be understood that the embodiments discussed herein may be practiced in other chambers capable of providing high density plasma.

[0025] Figure 1 illustrates a cross sectional side view of a processing chamber 100, according to one embodiment of the present disclosure. A substrate 102 is shown on a substrate surface 120 within a chamber body 104. In one embodiment, the substrate 102 includes a dielectric material (e.g., SiO₂, SiO_xN_y), a semiconductive material (e.g.,

silicon or doped silicon), a barrier material (SiN_x , SiO_xN_y), or a combination thereof. The processing chamber 100 also includes a lid assembly 106, a bottom 118 disposed opposite the lid assembly 106, and a pedestal or substrate support assembly 108 disposed between the lid assembly 106 and the bottom 118. The lid assembly 106 is disposed at an upper end of the chamber body 104, and the substrate support assembly 108 is at least partially disposed within the chamber body 104. The substrate support assembly 108 is coupled to a shaft 110. The shaft 110 is coupled to a drive 112 that moves the substrate support assembly 108 vertically (in the Z direction) within the chamber body 104. The substrate support assembly 108 of the processing chamber 100 shown in Figure 1 is in a processing position. However, the substrate support assembly 108 may be lowered in the Z direction to a position adjacent to a transfer port 114.

[0026] The lid assembly 106 may include a backing plate 122 that rests on the chamber body 104. The lid assembly 106 also functions as a plasma source 128. To function as the plasma source 128, the lid assembly 106 includes one or more inductively coupled plasma generating components, or inductive coupler 130. Each of the one or more inductive couplers 130 may be a single inductive coupler 130, two inductive couplers 130, or more than two inductive couplers 130, are simply described as inductive couplers 130 hereafter. Each of the one or more inductive couplers are coupled across a power source and ground 133. Although Figure 1 depicts each of the inductive couplers 130 connected to the power source and ground 133 in series, a connection in parallel is also contemplated such that each inductive coupler 130 is connected and controlled independently to the power source and ground 133. In some embodiments, ground 133 is a capacitor. The power source includes a match circuit or a tuning capability for adjusting electrical characteristics of the inductive couplers.

[0027] Each of the dielectric windows 138 are supported by the support member 136. Each of the one or more inductive couplers or portions of the one or more inductive couplers are positioned on or over a respective dielectric window 138. Each of the one or more inductive couplers 130 is configured to create an electromagnetic field that energizes a process gases into a plasma in the processing region 126 as gas is flowing into the processing region 126. In some embodiments, process gases from the gas source are provided to the processing region 126 via conduits in the support

members 136. The volume or flow rate of gas(es) entering and leaving the processing region 126 are controlled in different zones of the processing region 126. Zone control of processing gases is provided by a plurality of flow controllers, such as mass flow controllers 142, 143 and 144. For example, the flow rate of gases to peripheral or outer zones of the processing region 126 is controlled by the flow controllers 142, 143, while the flow rate of gases to a central zone of the processing region 126 is controlled by the flow controller 144. When chamber cleaning is required, cleaning gases from a cleaning gas source is flowed to the processing region 126 within which the cleaning gases are energized into ions, radicals, or both. The energized cleaning gases flow into the processing region 126 in order to clean chamber components. In one embodiment, the process gas(es) includes argon (Ar), nitrogen (N₂), helium (He), oxygen (O₂), carbon dioxide (CO₂), hydrogen (H₂), ammonia (NH₃), phosphine, nitrogen trifluoride (NF₃), fluorine (F₂), sulfur hexafluoride (SF₆), silane (SiH₄), tetraethyl orthosilicate (TEOS), water vapor (H₂O), or a combination thereof.

[0028] The processing chamber 100 further includes a controller 116. The controller 116 is in communication with the processing chamber 100 and is used to control processes of the process chamber 100. The processing chamber 100 includes a plurality of sensors (not shown) disposed therein for measures parameters such as temperature, gas flow, deposition rate, and power.

[0029] Figure 2A illustrates a schematic cross-sectional perspective view of a portion of an antenna array 250 with an electrode 255 disposed below a dielectric window 138. Figure 2B illustrates a schematic bottom view of a portion of the antenna array 250 with an electrode 255 disposed below the dielectric window. Figure 2C illustrates a schematic cross-sectional side view of a portion of the antenna array 250 with an electrode 255 disposed below the dielectric window.

[0030] Each inductive coupler 130 includes an antenna 202 disposed proximate to one or more corresponding dielectric windows 138 and to a distribution line coupled to a matching network (e.g., power source). In some embodiments, each antenna 202 is disposed over and at least partially surrounds interfaces of adjacent dielectric windows 138. Each antenna 202 is disposed over one or more dielectric windows 138 such that base portions 203, 302 are positioned over the dielectric windows 138. The first and second base portions 203, 302 is made up of first base portions 203 oriented

at an angle relative to the second base portions 302, such as perpendicular to second base portion 302 and disposed along an X-axis. The second base portions 302 are shown along a Y-axis. Each of the second base portions 302 are parallel with respect to one another and each of the first base portions 203 are parallel with respect to one another.

[0031] In the illustrated embodiment, the support members 136 include interface members 223 to form a grid to support a portion of the perimeter or the edge of the dielectric window 138. This grid creates a longitudinal interface members 223A and a latitudinal interface members 223B. The longitudinal interface member 223A is perpendicular with the second base portions 302 of the antenna 202. The latitudinal interface members 223B is perpendicular with the first base portions 203 of the antenna 202. Other additional portions are also contemplated to form alternative shapes and angles relative to one another, such as a triangular antenna or a hexagonal antenna. Angles between portions can be about 60 degrees to about 170 degrees, such as about 80 degrees to about 120 degrees, such as about 90 degrees to about 100 degrees.

[0032] In some embodiments, the interface members 223 extend upward toward the backing plate 122 such that the interface members 223 are surrounding the first and second base portions 203, 302 of the antenna 202. In such embodiments, the interface members 223 remain electrically isolated from the first and second base portions 203, 302 of the antenna 202.

[0033] The interface member 223 includes gas ports to allow gases to flow into the processing region 126 at predetermined flow rates. Each interface member 223 includes a ledge or shelf that supports a portion of the perimeter or an edge of the dielectric window 138. The interface member 223 may further include gas distribution arms 270. The gas distribution arms 270 extend from an intersection region 225 of a longitudinal interface member 223A and latitudinal interface members 223B and towards the center of the dielectric window 138. The gas distribution arm 270 extends from the intersection region 225 at an angle between 1° and 89°, such as between 30° and 65°.

[0034] The reduced lateral surface area of the multiple dielectric windows 138 allows the use of dielectric materials as a physical barrier between the vacuum

environment and plasma in the processing region 126 and the atmospheric environment in which the adjacent inductive coupler 130 is typically positioned, without imposing large stresses therein based on a large area supporting the atmospheric pressure load.

[0035] In some embodiments, during processing, the processing region 126 has a vacuum pressure of about 10 mTorr to about 3 Torr. Materials for the plasma source 128 are chosen based on one or more of electrical characteristics, strength and chemical stability. The inductive couplers 130 are made of an electrically conductive material. The backing plate 122 and the support members 136 are made of a material that is able to support the weight of the supported components and atmospheric pressure load, which may include a metal or other similar material. The backing plate 122 and the support members 136 can be made of a non-magnetic material (e.g., non-paramagnetic or non-ferromagnetic material), such as an aluminum material. The dielectric windows 138 are made of a quartz, alumina or sapphire materials. In some embodiments, the dielectric windows 138 include copper, silver, aluminum, tungsten, molybdenum, titanium, combinations thereof, or alloys thereof.

[0036] In some embodiments, the RF power supplied to the inductive coupler 130 is about 1 kW to about 500 kW, such as about 5 kW to about 50 kW, such as about 10 kW to about 30 kW, such as about 15 kW to about 20 kW. In some embodiments, the RF power is supplied at a frequency of about 100 kHz to about 500 MHz frequency depending on the predetermined process and operating parameters. In some embodiments, the RF power is supplied to sustain a plasma having a plasma density of about $1 \times 10^{10} \text{ cm}^{-3}$ to about $10 \times 10^{12} \text{ cm}^{-3}$.

[0037] As shown in Figures 2A-2C, the electrode 255 is disposed below the dielectric window 138. The electrode 255 may include an electrode facemask or an electrode grill structure. The electrode 255 includes a plurality of connector arms 256 configured to connect the electrode 255 to the adjacent longitudinal interface members 223A. The connector arms 256 may be at an angle towards the longitudinal interface members 223A of about 30° to about 50° , such as about 40° . The electrode 255 has a width w and a length l . The length l of the electrode 255 is from about 50 cm to about 200 cm, such as about 75 cm and about 100 cm. The width w of the electrode 255 is from about 25 cm and about 150 cm, such as about 50 cm and about 75 cm.

In some embodiments, the electrode 255 is centered on the dielectric window 138. In other embodiments, the electrode 255 is offset with regard to a center of the dielectric window 138.

[0038] The electrode 255 may enable increased uniformity control and stoichiometric control proximate to the electrode 255 during processing of the substrate 102. The uniformity and stoichiometry may be better controlled due to improved control of the electromagnetic field proximate to the electrode 255. The length l and the width w of the electrode 255 may be adjusted to control the electromagnetic field proximate to the electrode 255. The offset of the electrode 255 with regard to the dielectric window 138 may be adjusted to control the electromagnetic field proximate to the electrode 255.

[0039] Figure 3 illustrates a top plan view of an antenna 202 of an inductive coupler 130. The antenna 202 configuration depicts one antenna 202 that can be arranged with adjacent antennas 202 having substantially the same configuration in a pattern across the lid assembly 106. The antenna 202 includes a conductor pattern that is a rectangular spiral shape. Other spiral shapes are contemplated based on a shape the substrate, such as a triangle or a hexagon. Electrical connections include an electrical input terminal 295A and an electrical output terminal 295B. Each of the one or more inductive couplers 130 of the lid assembly 106 are connected in series and/or in parallel. In some embodiments, the electrode shape is selected based on the shape of the base of the antenna, such as first and second base portions 203 and 302. In some embodiments, the electrode shape is a rounded L shaped with portions that are angled relative to the portions 302, such as substantially perpendicular to second base portions 302, and with electrode portions that are angled relative to the first base portions 203, such as substantially perpendicular to first base portions 203.

[0040] Figure 4 illustrates a schematic perspective view of a portion an antenna sub-array 470 of the antenna array 250. The antenna array 250 includes a plurality of gas conduits 465. The gas conduits 465 allows for the flow of the process gas from the gas source through the support members 136 and interface members 223 to the processing region 126. In the illustrated embodiment, the gas conduits 465 are positioned in the center of each antenna 202 and between the second base portions

302 of adjacent antennas 202. In other embodiments, however, other gas conduit 465 positions are also contemplated.

[0041] The lid assembly 106 having the inductive coupler 130 described herein can be used for HDP process chambers. The antennas 202 of the inductive coupler 130 are capable of controlling a degree of ICP coupling to the plasma at a variety of RF powers. The antennas 202 can be a helix type RF coil of either vertical or flat spiral coils of concentric or rectangular shapes, and of non-flat or vertical shapes, such as a rectangular coil, a hexagonal coil, or a triangular coil. The adjacent coil portions are arranged to locally drive plasma and to interfere or cancel RF magnetic fields generated in order to control constructive or destructive coupling based on coil design. In the illustrated embodiment, the rectangular antenna 202 has 3 turns. However, greater or lesser turns are anticipated.

[0042] In various embodiments, the antennas 202 of the antenna sub-arrays 470 are assembled in a symmetrical fashion, where each of the antennas 202 is a mirror image of the adjacent antenna 202, and each antenna sub-array 470 is a mirror image of the adjacent mirror sub-array 470. Therefore, the currents flowing along an of the first base portion 203 or second base portion 302 of an antenna 202 has a mirror image from the adjacent antenna 202. As a result, all of the adjacent antennas 202 and antenna sub-arrays 470 have equivalent currents in both magnitude and direction. Further, the electromagnetic fields produced by the antennas 202 and antenna sub-arrays 470 are enhanced due to constructive (e.g., in-phase) interference, with the highest electromagnetic field occurring at the interfaces between the antenna sub-arrays 470.

[0043] Figure 5A illustrates a schematic cross-sectional perspective view of a portion of an antenna array 550 with an electrode 555 disposed within a dielectric window 138. Figure 5B illustrates a schematic cross-sectional side view of a portion of the antenna array 550 with an electrode 555 disposed within the dielectric window 138. The antenna array 550 may be used in place of the antenna array 250. The electrode 555 includes a plurality of connector arms configured to connect the electrode 555 to the adjacent longitudinal interface members 223A. In some embodiments, the electrode 555 does not include a plurality of connector arms.

[0044] Figure 6A illustrates a schematic cross-sectional perspective view of a portion of an antenna array 650 with an electrode 655 disposed below a dielectric window 138. Figure 6B illustrates a schematic top view of a portion of the antenna array 650 with an electrode 655 disposed below the dielectric window 138. Figure 6C illustrates a schematic cross-sectional side view of a portion of the antenna array 650 with an electrode 655 disposed below the dielectric window 138. The antenna array 650 may be used in place of the antenna array 250. The electrode includes a plurality of connector arms 656 configured to connect the electrode 655 to the adjacent longitudinal interface members 223A.

[0045] Figure 7 illustrates a control schematic 700 for use within the processing chamber 100. The controller is part of a process system for storing instructions that, when executed, cause the process system to process a substrate within a processing chamber according to this disclosure. In one embodiment, the instructions cause the process system to process a substrate within a processing chamber by flowing a process gas through the plurality of interface members 223 having a gas port into a processing region, forming a plasma using a plurality of inductive couplers, and depositing the gas on the substrate. The processing chamber includes a plurality of sensors to facilitate deposition on the substrate, measure the deposition rate, and control a power supply, a temperature, and a gas flow rate. The controller 116 receives data or input from sensor readings 702 from the sensors within the processing chamber 100. The controller 116 is equipped with or in communication with a system model 706 of the processing chamber 100. The system model includes heating modules, gas flow modules, power modules, and deposition modules. The system model 706 is a program configured to estimate or determined the gas flow, heating, deposition, and power within the processing chamber 100 throughout the process. The controller 116 is further configured to store readings and calculations.

[0046] The readings and calculations 704 include previous sensor readings 702 as well as any other previous sensor readings within the processing chamber 100. The readings and calculations 704 further include the stored calculated values from after the sensor readings 702 are measured by the controller 116 and run through the system model 706. Therefore, the controller 116 is configured to both retrieve stored readings and calculations 704 as well as save readings and calculations 704 for future

use. Maintaining previous readings and calculations enables the controller 116 to adjust the system model 706 over time to reflect a more accurate version of the processing chamber 100.

[0047] In embodiments described herein, the controller 116 includes a programmable central processing unit (CPU) that is operated with a memory and a mass storage device, an input control unit, and a display unit (not shown). The controller 116 monitors the precursor, process gas, and purge gas flow. Support circuits are coupled to the CPU for supporting the processor in a conventional manner. In some embodiments, the controller 116 includes multiple controllers 116, such that the stored readings and calculations 704 and the system model 706 are stored within a separate controller from the controller 116 which operations the processing chamber 100. In other embodiments, all of the system model 706 and the stored readings and calculations 704 are saved within the controller 116.

[0048] The controller 116 is configured to control the heating, power, deposition, and gas flow through the processing chamber 100 by controlling aspects of the gas flow controls 708. The gas flow controls 708 the process gas source, the purge gas source, and the exhaust pump. The controller 116 may also control the shaft 110 within the processing chamber 100.

[0049] The controller 116 is configured to adjust the output to each of the gas flow controls 708 based off the sensor readings 702, the system model 706, and the stored readings and calculations 704. The controller 116 includes embedded software and a compensation algorithm to calibrate deposition on the substrate 102. The deposition on the substrate 102 may be measured as the substrate leaves the processing chamber or between process operations to provide a reference for deposition rates measured using the sensors. The controller 116 may include a machine-learning algorithm and may use a regression or clustering technique. The algorithm is an unsupervised or a supervised algorithm.

[0050] Figure 8 is a block flow diagram of a method 800 of depositing films over a substrate according to an embodiment. The method includes, in operation 802, flowing a precursor gas to a processing region 126. In operation 804, a radiofrequency power is provided to an inductive coupler disposed above the processing region 126. In operation 806, plasma is distributed to a process region 126 of a high-density plasma

process chamber 100. The plasma has a plasma density of about $1 \times 10^{10} \text{ cm}^{-3}$ to about $10 \times 10^{12} \text{ cm}^{-3}$ and each gas volume is maintained at a vacuum volume of about 10 mTorr to about 3 Torr. A film is deposited on a substrate, such as a rectangular substrate, the film is composed of silicon oxide, silicon nitride, silicon-oxide-nitride, or combinations thereof.

[0051] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure 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. An antenna array, comprising:
a plurality of inductive couplers;
a dielectric window disposed below a plurality of antennas;
a plurality of support members comprising an interface member configured to support the dielectric window; and
an electrode disposed under the antenna array and proximate to the dielectric window, wherein the electrode is connected to the interface member of the plurality of support members.
2. The antenna array of claim 1, wherein the electrode is disposed over the dielectric window.
3. The antenna array of claim 1, wherein the plurality of interface members further include a plurality of gas distribution arms extending from an intersection region of the interface members towards a center of a dielectric window disposed on the plurality of interface members.
4. The antenna array of claim 1, wherein the electrode is disposed below the dielectric window.
5. The antenna array of claim 1, wherein the plurality of antennas include a plurality of coils forming a rectangular coil, a triangular coil, or a hexagonal coil.
6. The antenna array of claim 1, wherein the electrode comprises a plurality of connector arms, wherein the connector arms are at an angle towards a longitudinal interface members of an interface members of about 30° to about 50°.
7. The antenna array of claim 1, wherein the electrode comprises a length and a width, wherein the length is about 75 cm to about 100 cm and the width is about 50 cm to about 75 cm.

8. The antenna array of claim 1, wherein the electrode is offset from a center of the dielectric window.
9. A controller of a process system storing instructions that, when executed by a processor, causes the system to:
- process a substrate within a processing chamber by:
 - flowing a process gas through a plurality of interface members having a gas port into a processing region;
 - forming a plasma using an electromagnetic field generated by a plurality of inductive couplers;
 - controlling a uniformity and a stoichiometry of the electromagnetic field using an electrode disposed under the plurality of inductive couplers and proximate to a dielectric window supported by the plurality of interface members; and
 - depositing a film on the substrate;
 - measure a deposition rate, a power supply, a temperature, and a gas flow rate using a plurality of sensors;
 - calculate a deposition rate on the substrate; and
 - adjust a processing chamber parameter based on the deposition rate, the power supply, the temperature, or the gas flow rate.
10. The controller of claim 9, wherein the electrode is disposed over a dielectric window and under the plurality of inductive couplers.
11. The controller of claim 9, wherein the electrode is disposed within a dielectric window.
12. The controller of claim 9, wherein the electrode is disposed below a dielectric window.

13. The controller of claim 9, wherein the electrode comprises a length and a width, wherein the length is about 75 cm to about 100 cm and the width is about 50 cm to about 75 cm.

14. The controller of claim 9, wherein the electrode comprises a plurality of connector arms, wherein the connector arms are at an angle towards a longitudinal interface member of the plurality of interface members of about 30° to about 50°.

15. The controller of claim 9, wherein the plurality of interface members further include a plurality of gas distribution arms extending from an intersection region of the interface members towards the center of a dielectric window disposed on the plurality of interface members.

16. An antenna array, comprising:
a plurality of interface members;
a plurality of dielectric windows supported by the plurality of interface members;
a plurality of inductive couplers, comprising a plurality of antennas disposed over the plurality of dielectric windows; and
an electrode disposed under the inductive couplers and embedded within the dielectric window.

17. The antenna array of claim 16, wherein the plurality of interface members further comprise a plurality of gas ports.

18. The antenna array of claim 16, wherein the electrode comprises a plurality of connector arms, wherein the connector arms are at an angle towards a longitudinal interface member of the plurality of interface members of about 30° to about 50°.

19. The antenna array of claim 16, wherein the plurality of interface members further include a plurality of gas distribution arms extending from an intersection

region of the interface members towards the center of a dielectric window disposed on the plurality of interface members.

20. The antenna array of claim 16, wherein the electrode comprises a length and a width, wherein the length is about 75 cm to about 100 cm and the width is about 50 cm to about 75 cm.

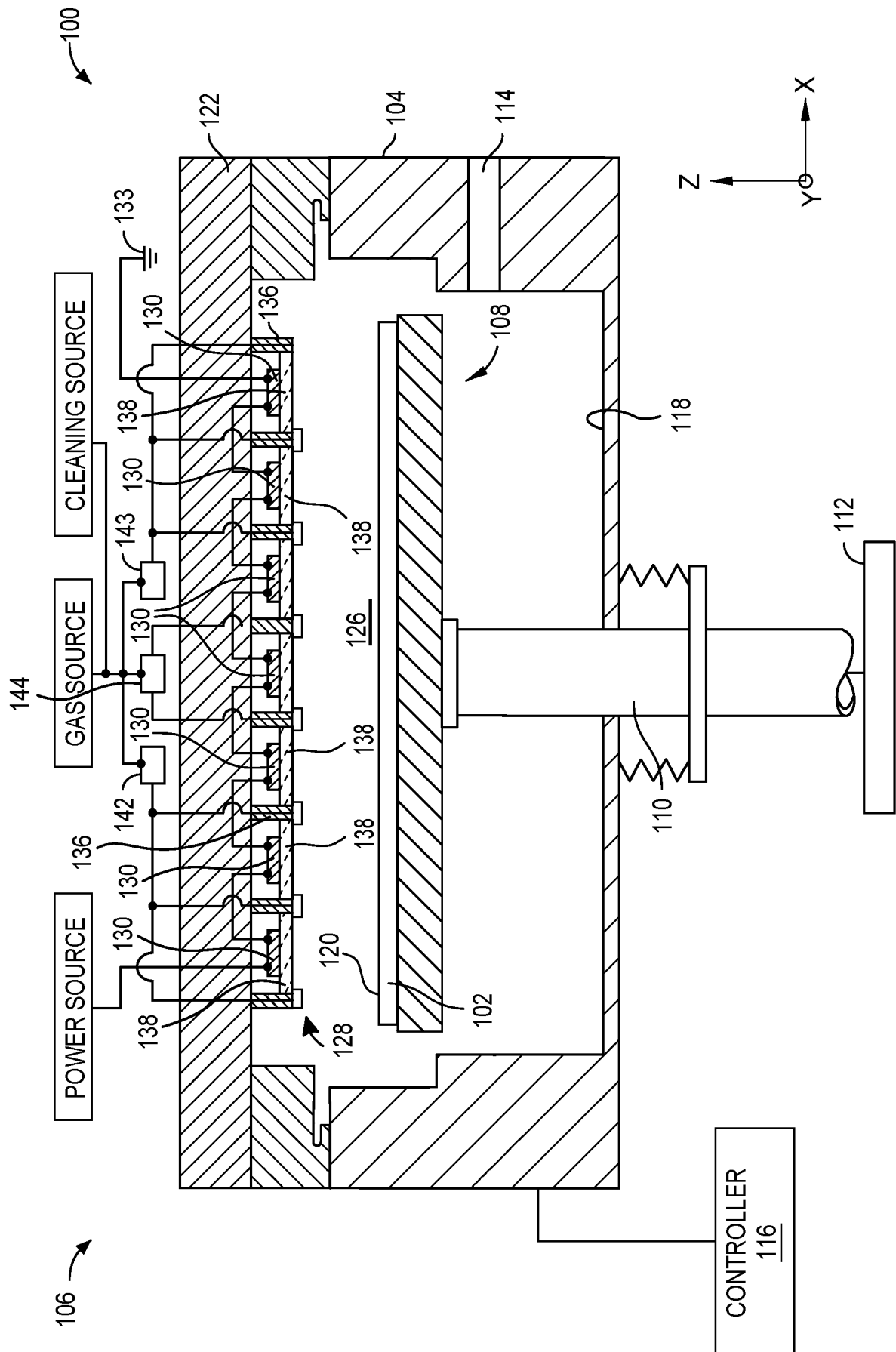
$\frac{1}{8}$ 

FIG. 1

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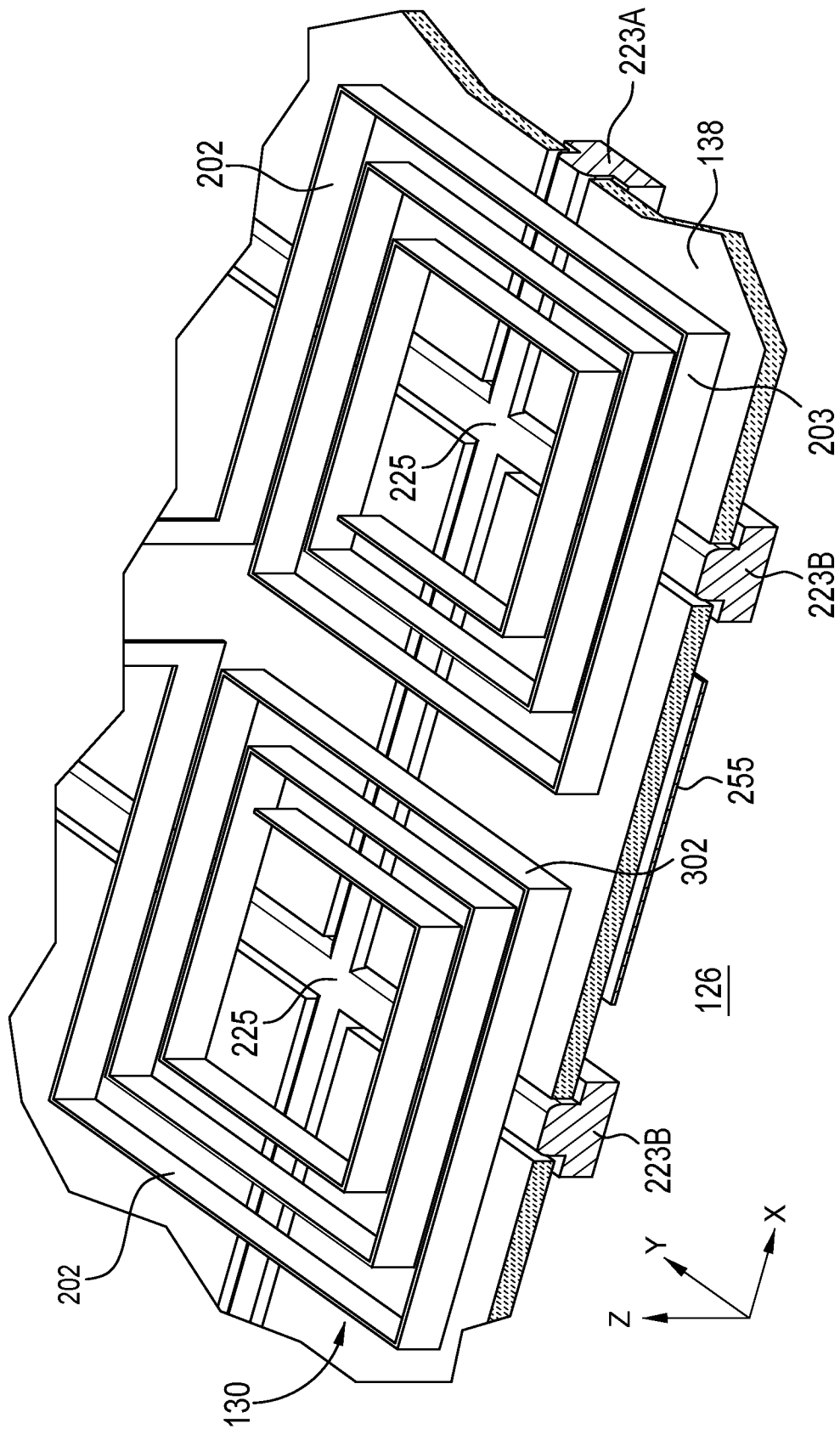
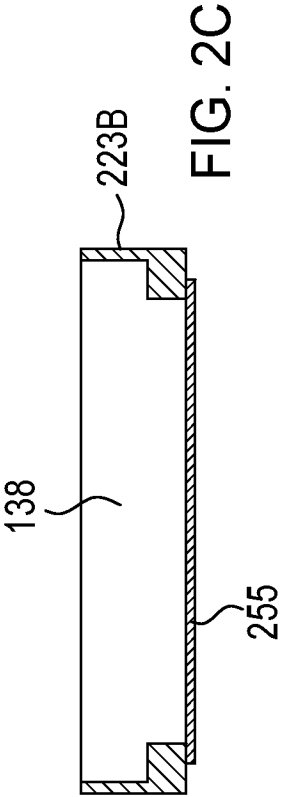
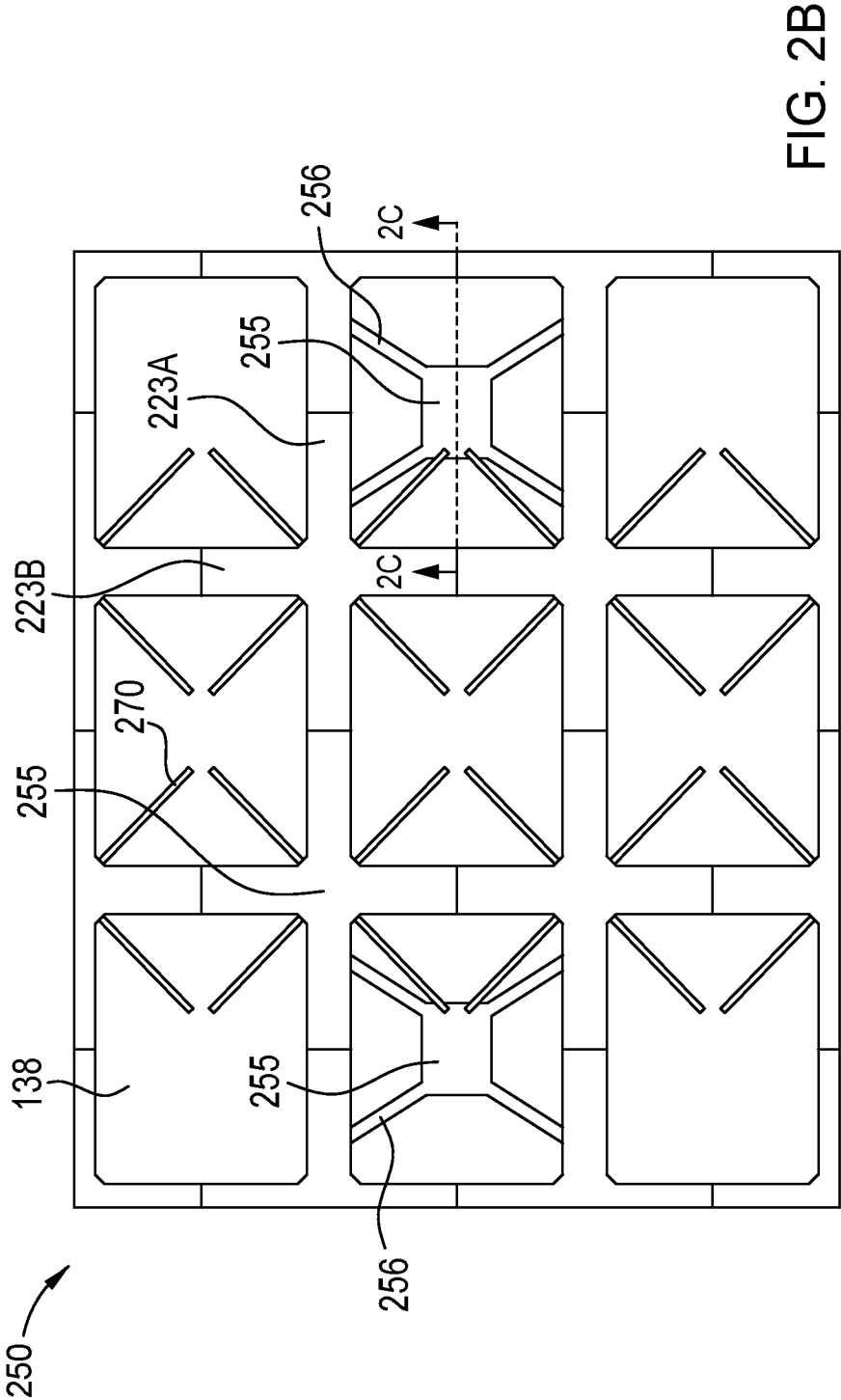
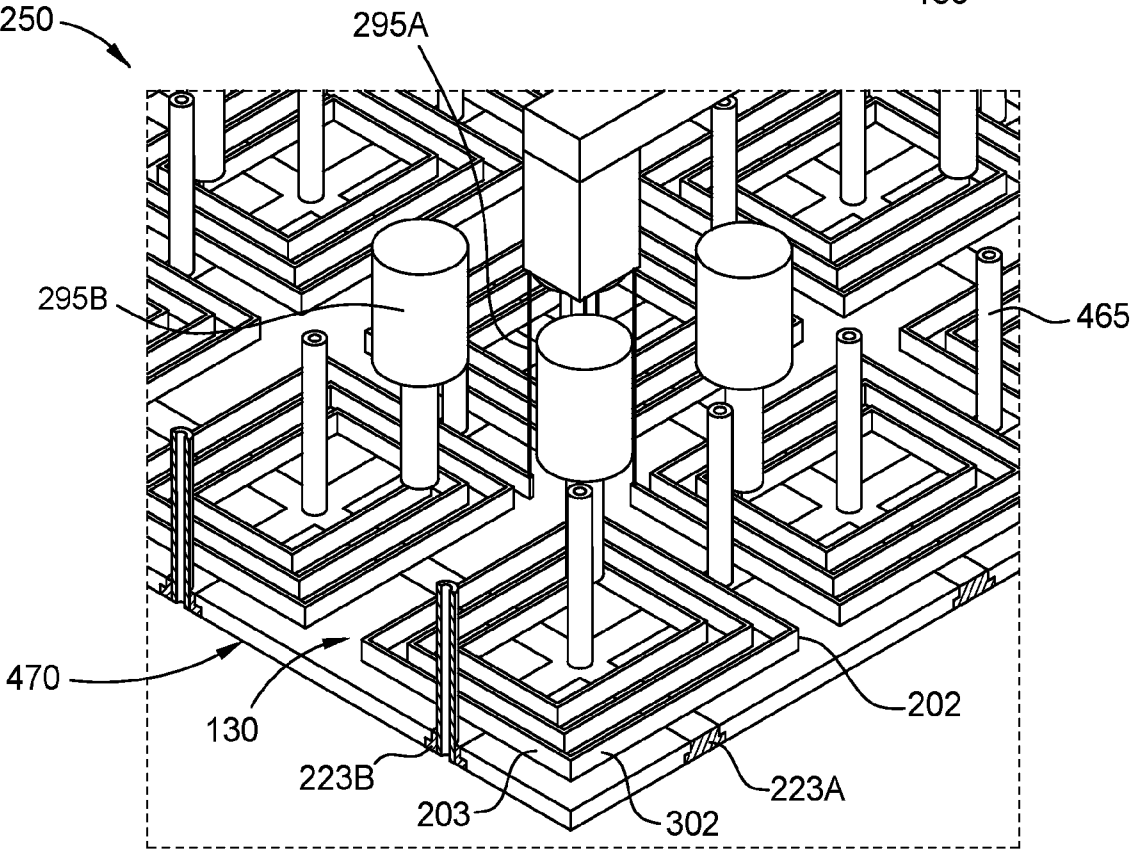
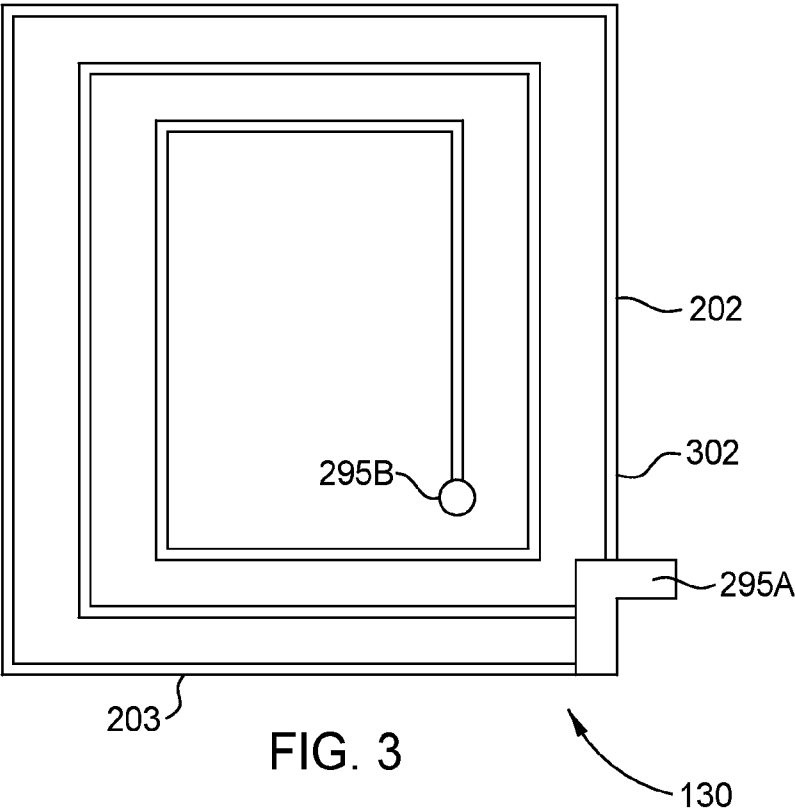
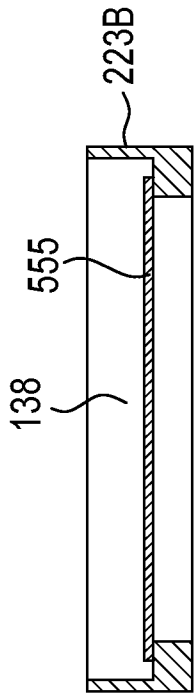
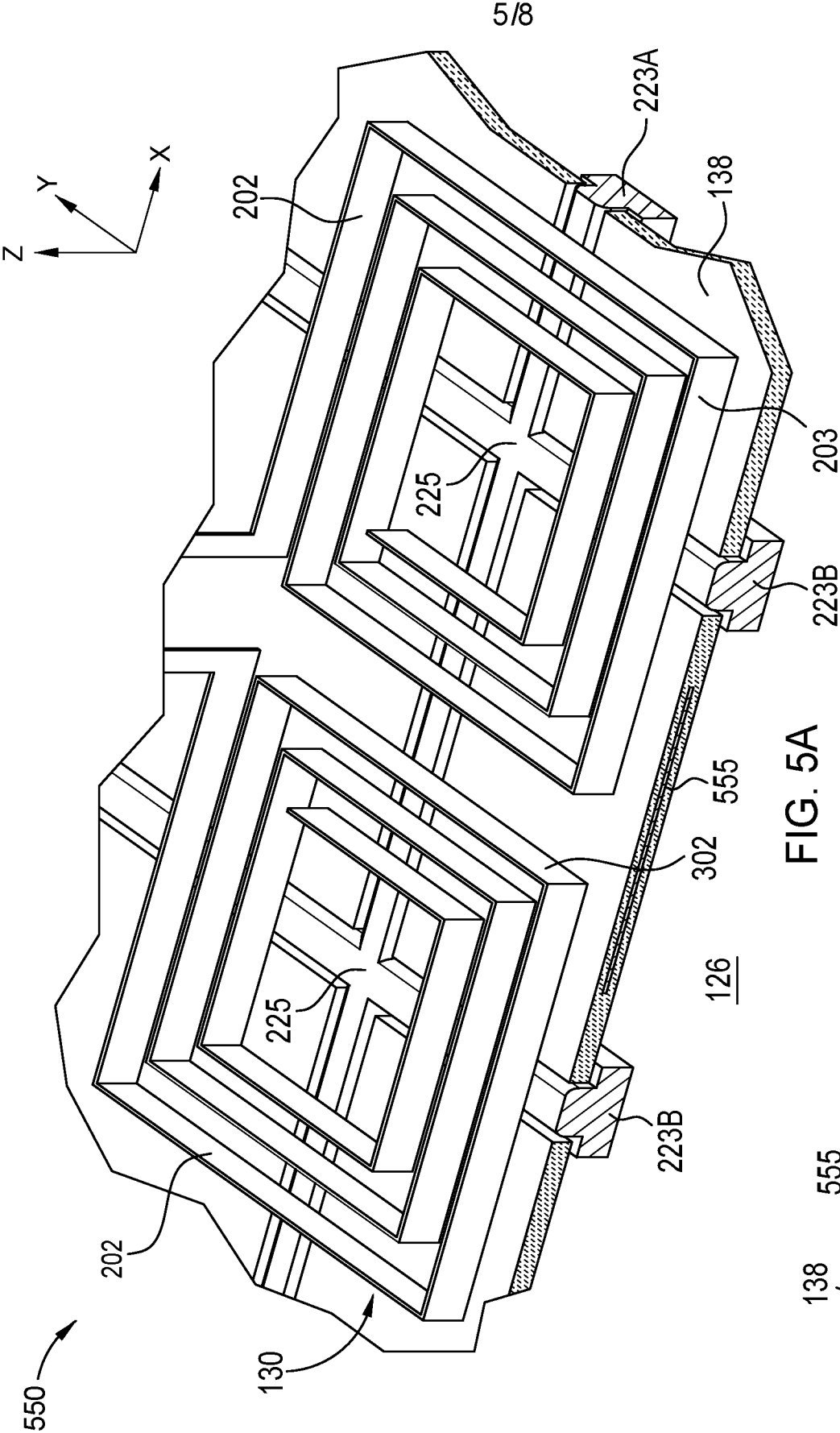


FIG. 2A



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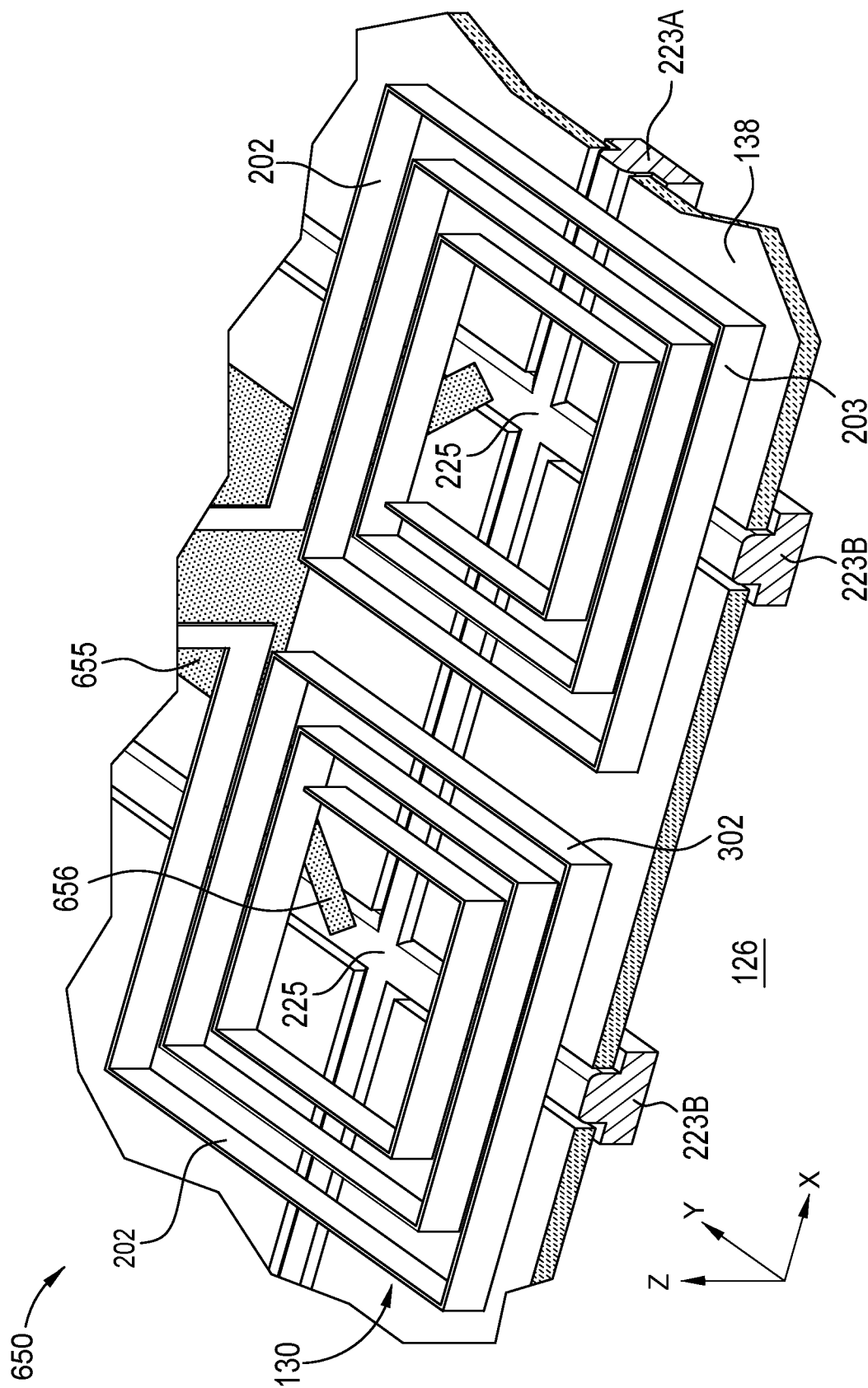


FIG. 6A

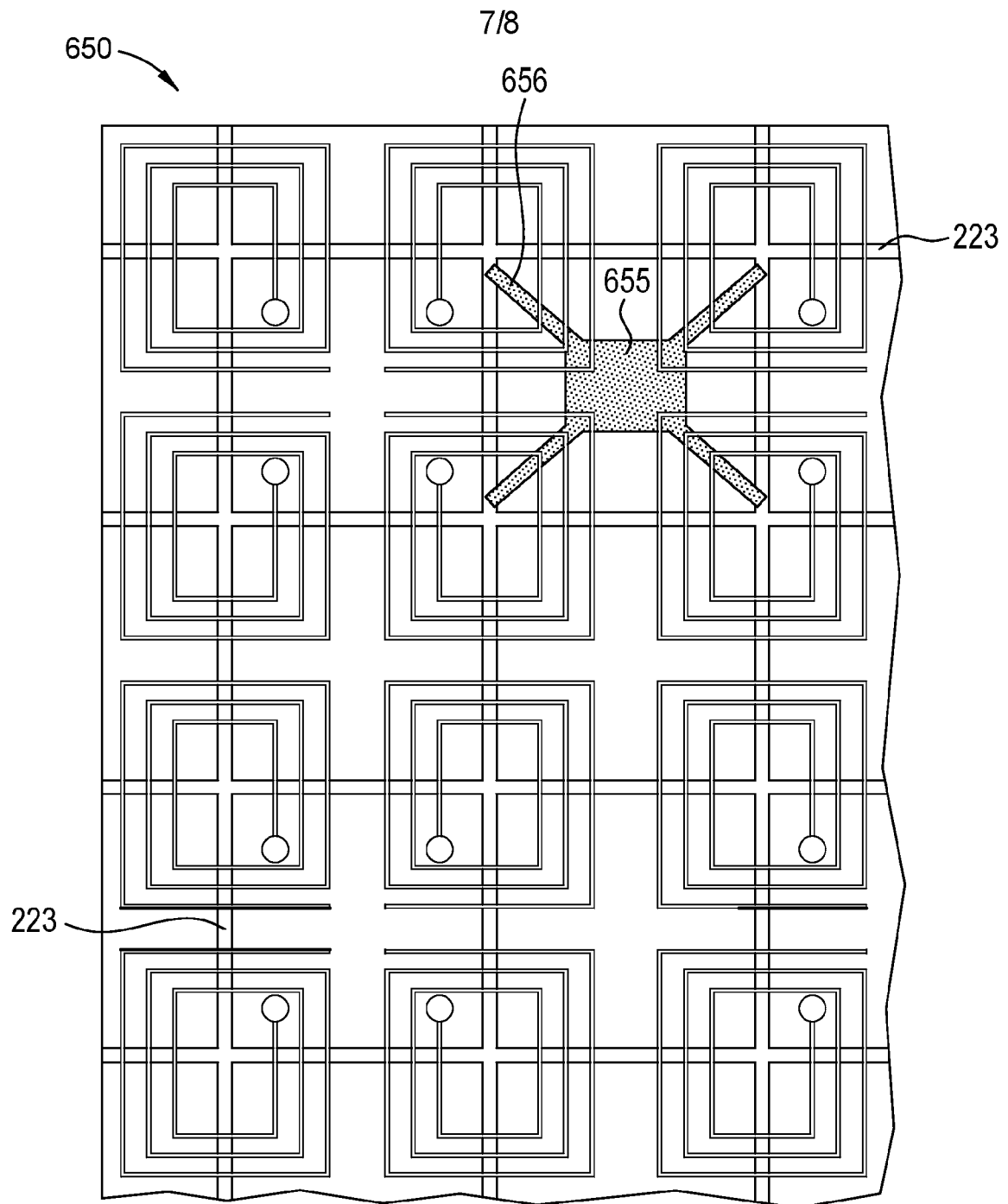


FIG. 6B

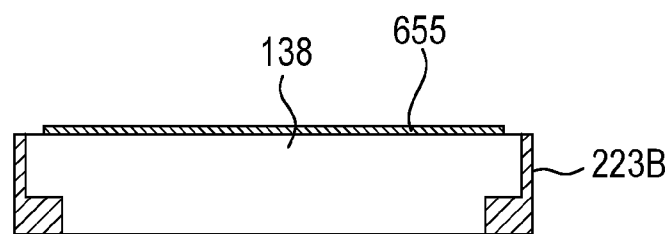


FIG. 6C

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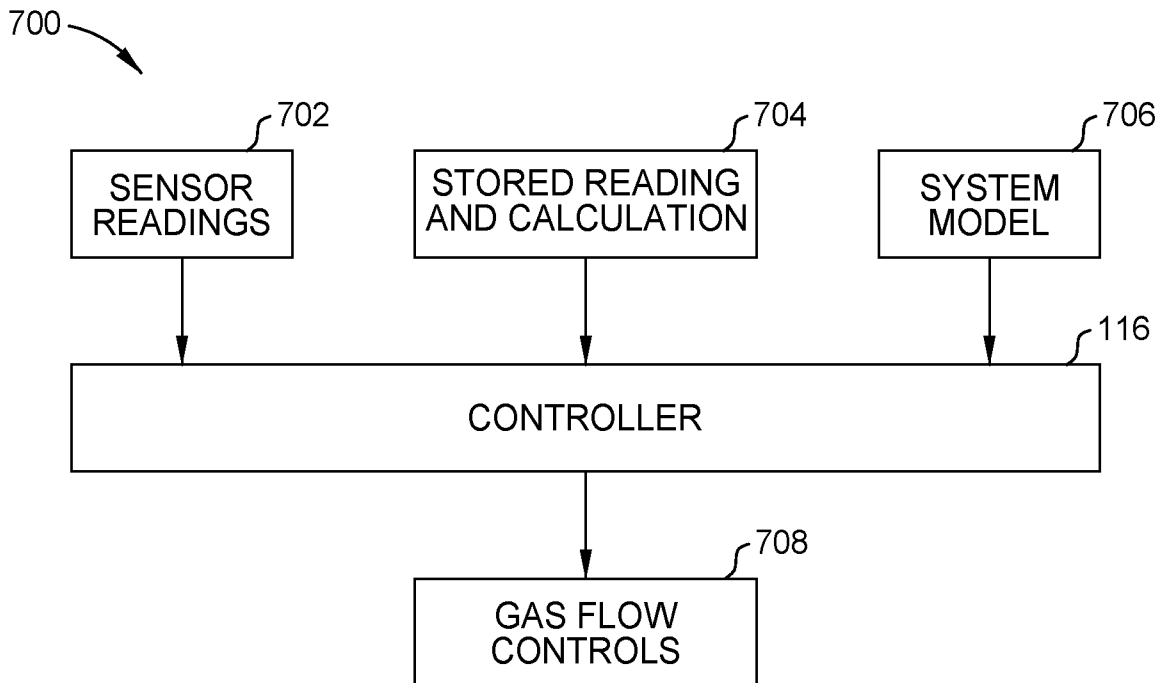


FIG. 7

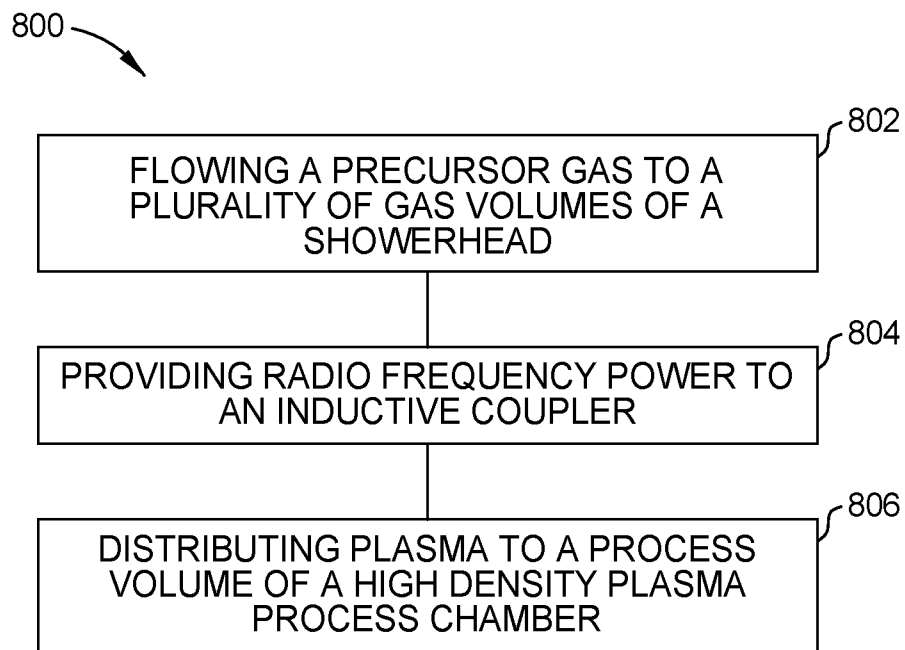


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/054381

A. CLASSIFICATION OF SUBJECT MATTER H01J 37/32(2006.01)i; H01Q 21/06(2006.01)i; H01Q 1/38(2006.01)i; H01Q 1/36(2006.01)i; H01Q 1/26(2006.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H01J 37/32(2006.01); C23C 16/00(2006.01); C23C 16/455(2006.01); C23C 16/505(2006.01); C23C 16/54(2006.01); C23F 1/00(2006.01); H01Q 1/36(2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Korean utility models and applications for utility models Japanese utility models and applications for utility models Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) eKOMPASS(KIPO internal) & Keywords: antenna, plasma, chamber, interface member, electrode, dielectric window		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008-0303744 A1 (MASAKI HIRAYAMA et al.) 11 December 2008 (2008-12-11) See paragraphs 39-56, claims 1-26 and figures 1-5.	1-20
A	US 2016-0155613 A1 (TOKYO ELECTRON LIMITED) 02 June 2016 (2016-06-02) See paragraphs 80-118, claims 1-14 and figures 1-3.	1-20
A	WO 2023-096775 A1 (APPLIED MATERIALS, INC.) 01 June 2023 (2023-06-01) See paragraphs 19-26 and figures 1-2.	1-20
A	WO 2021-126172 A1 (APPLIED MATERIALS, INC.) 24 June 2021 (2021-06-24) See paragraphs 25-37 and figures 1-2B.	1-20
A	US 2008-0210378 A1 (WEON-MOOK LEE) 04 September 2008 (2008-09-04) See paragraphs 57-78 and figures 5-10.	1-20
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “D” document cited by the applicant in the international application “E” earlier application or patent but published on or after the international filing date “L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) “O” document referring to an oral disclosure, use, exhibition or other means “P” document published prior to the international filing date but later than the priority date claimed “T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention “X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art “&” document member of the same patent family		
Date of the actual completion of the international search 17 February 2025		Date of mailing of the international search report 18 February 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon 35208, Republic of Korea Facsimile No. +82-42-481-8578		Authorized officer LEE, Kang Ha Telephone No. +82-42-481-5687

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2024/054381

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