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(54) Title: DIVERGENCE MEASUREMENT SYSTEM FOR ION BEAM SUBSTRATE PROCESSING SYSTEMS

(57) Abstract: A divergence measurement system includes an ion beam sensor including an enclosure including a first aperture on a first surface of the enclosure. A Faraday cup is arranged in the enclosure and includes a second aperture to receive ions generated by a plasma source and to generate a current signal based thereon. A first positioning device moves the Faraday cup within the enclosure.

DIVERGENCE MEASUREMENT SYSTEM FOR ION BEAM SUBSTRATE PROCESSING SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/432,586
5 filed on December 14, 2022. The entire disclosure of the application referenced above is
incorporated herein by reference.

FIELD

[0002] The present disclosure relates to ion beam substrate processing systems, and
more particularly to a divergence measurement system for ion beam substrate
10 processing systems.

BACKGROUND

[0003] The background description provided here is for the purpose of generally
presenting the context of the disclosure. Work of the presently named inventors, to the
extent it is described in this background section, as well as aspects of the description that
15 may not otherwise qualify as prior art at the time of filing, are neither expressly nor
impliedly admitted as prior art against the present disclosure.

[0004] Substrate processing systems may be used to treat substrates such as
semiconductor wafers. The substrate treatments may include deposition, etching,
cleaning, and other treatments. Substrate etching may be performed using an ion beam
20 generated by a plasma source. A substrate is arranged on a substrate support in a
processing chamber. The ions pass through a grid arranged between the plasma source
and the processing chamber and impact a substrate arranged on a substrate support.

[0005] Divergence of ions in the ion beam is an important parameter of ion beam etching
processes. Small shifts in a divergence angle of the ion beam may cause changes to
25 critical dimensions (CD) of the substrate. However, it is difficult to measure the
divergence angle of the ion beam at different locations of the substrate support.

SUMMARY

[0006] A divergence measurement system includes an ion beam sensor including an
enclosure including a first aperture on a first surface of the enclosure. A Faraday cup is

arranged in the enclosure and includes a second aperture to receive ions generated by a plasma source and to generate a current signal based thereon. A first positioning device moves the Faraday cup within the enclosure.

[0007] In other features, the first positioning device is configured to move the Faraday cup within the enclosure in a plane that is parallel to the first surface of the enclosure including the first aperture. A current sensor senses the current signal. A controller is configured to receive the current signal from the current sensor and to calculate a divergence angle based thereon. The controller is configured to calculate a beam diameter for a predetermined location based on a predetermined percentage of a maximum current value measured by the current sensor and to calculate the divergence angle based on the beam diameter.

[0008] In other features, a second positioning device is configured adjust a position of the enclosure and the Faraday cup relative to a substrate support of a processing chamber. The first positioning device is configured to move the Faraday cup within the enclosure in a plane that is transverse to the first surface of the enclosure including the first aperture.

[0009] In other features, a current sensor senses the current signal. A controller is configured to receive the current signal from the current sensor and to calculate a divergence angle based thereon. A second positioning device is configured adjust a position of the enclosure and the Faraday cup relative to a substrate support of a processing chamber.

[0010] In other features, M of the ion beam sensor arranged on a platen.

[0011] A divergence measurement system includes an ion beam sensor including an enclosure including one or more side walls, a first surface, and a second surface including an aperture. A plurality of annular projections extends inwardly into the enclosure from at least one of the side walls and the first surface to define a plurality of measurement regions in the enclosure. A plurality of current sensors measures current in at least two of the plurality of measurement regions.

[0012] In other features, a positioning device is configured to adjust a position of the enclosure relative to a substrate support of a processing chamber. The plurality of annular projections includes a first annular projection arranged on the first surface and a second annular projection arranged on the first surface within the first annular projection.

The plurality of annular projections includes a first annular projection arranged on the one or more side walls and a second annular projection arranged on the one or more side walls spaced from the first annular projection.

[0013] In other features, a controller is configured to receive current signals from the plurality of current sensors and to calculate a divergence angle based thereon. The controller is configured to calculate a beam diameter for a predetermined location based on a predetermined percentage of a maximum current value measured by the plurality of current sensors and to calculate the divergence angle based on the beam diameter.

[0014] A divergence measurement system for a processing chamber receiving an ion beam from a plasma source includes an ion beam sensor including a capillary plate including a channel. A Faraday cup is connected to the capillary plate and includes an aperture aligned with the channel of the capillary plate. The Faraday cup is configured to receive ions generated by the plasma source and to generate a current signal based thereon. A tilt adjusting device is configured to adjust a tilt angle of the capillary plate and the Faraday cup to a plurality of tilt angles.

[0015] In other features, a positioning device is configured adjust a position of the ion beam sensor relative to a substrate support in the processing chamber. A current sensor senses the current signal. A controller is configured to receive the current signal at a plurality of tilt angles and to calculate a divergence angle based thereon. The controller is configured to calculate a beam diameter for a predetermined location based on a predetermined percentage of a maximum current value measured at the plurality of tilt angles and to calculate the divergence angle based on the beam diameter. The tilt adjusting device adjusts a tilt angle of substrate support to adjust the tilt angle of the capillary plate and the Faraday cup.

[0016] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims, and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0018] FIG. 1 is a functional block diagram of an example of an ion beam processing system for substrates that includes a divergence measurement system including an ion beam sensor according to the present disclosure;

[0019] FIGs. 2A and 2B illustrate examples of different ion beam divergence angles;

5 **[0020]** FIG. 3 illustrates an example of an ion beam divergence sensor including a Faraday cup arranged in an enclosure according to the present disclosure;

[0021] FIG. 4 is a graph illustrating an example of beam current as a function of lateral position of the Faraday cup in the enclosure;

10 **[0022]** FIG. 5 is a graph illustrating an example of calculated ion current as a function of lateral position of the Faraday cup in the enclosure;

[0023] FIG. 6 illustrates another example of a divergence measurement system including a Faraday cup arranged in an enclosure according to the present disclosure;

[0024] FIG. 7 is a graph illustrating an example of beam current as a function of vertical position of the Faraday cup in the enclosure;

15 **[0025]** FIG. 8 illustrates the location of first aperture of the enclosure relative to the second aperture of the Faraday cup;

[0026] FIG. 9 illustrates calculated ion current as a function of the vertical distance between the first and second apertures;

20 **[0027]** FIG. 10A illustrates another example of an ion beam divergence sensor including an enclosure with an aperture, a plurality of current sensors, and projections defining separate measurement regions according to the present disclosure;

[0028] FIG. 10B is a plan view of a bottom surface of the enclosure including annular projections according to the present disclosure;

25 **[0029]** FIGs. 11A to 11C illustrate another example of an ion beam divergence sensor including a capillary plate and a Faraday cup according to the present disclosure;

[0030] FIG. 12 illustrates a tilt axis of a substrate support and an ion beam divergence sensor arranged on the substrate support according to the present disclosure;

[0031] FIG. 13 illustrates a tilt adjusting device for the capillary plate and the Faraday cup according to the present disclosure; and

[0032] FIG. 14 illustrates an ion beam divergence sensor array including a plurality of ion beam divergence sensors arranged on a platen according to the present disclosure.

[0033] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

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DETAILED DESCRIPTION

[0034] The divergence angle of an ion beam corresponds to an angle that ions travel relative to a predetermined direction (such as vertical, horizontal, or another reference plane). One method for measuring the divergence angle of an ion beam is to etch hole patterns on a test substrate. Etch depth profiles are measured at various locations to
10 determine the divergence angle at that location. This approach is time consuming and less accurate than desired. A divergence measurement system according to the present disclosure includes an ion beam divergence sensor configured to measure the divergence angle in situ for ion beam processes such as etching.

[0035] Referring now to FIG. 1, an ion beam processing system 50 for substrates
15 includes a plasma source 60. While a specific type of plasma source using inductively coupled plasma (ICP) is shown, other plasma sources may be used. In this example, the plasma source 60 includes an enclosure 61 configured to contain the plasma during operation. The plasma source 60 includes a gas distribution device 62 configured to deliver and distribute plasma process gases in the enclosure 61. In some examples, the
20 gas distribution device 62 includes a gas plenum 63 and a plurality of gas through holes 65 extending through a surface of the gas plenum 63. In other examples, the gas distribution device 62 includes one or more gas injectors.

[0036] One or more inductive coils 64 are arranged around an outer surface of the enclosure 61. RF power is supplied to the one or more inductive coils 64. When
25 energized, the inductive coils 64 induce a magnetic field inside of the enclosure 61 to strike and maintain plasma. A grid 66 including one or more platens 67 with aligned through holes 69 is arranged between the plasma source 60 and a processing chamber 70. A substrate support 74 such as an electrostatic chuck (ESC) is arranged in the processing chamber 70. The ions pass through the apertures 69 in the grid 66 and impact
30 the substrate.

[0037] A positioning device 78 is configured to tilt and/or rotate the substrate support 74. A surface 80 of the substrate support 74 is configured to support and/or engage a

substrate 84 such as a semiconductor wafer during substrate treatment (such as during etching). The substrate 84 is not present during ion beam divergence measurement.

[0038] A gas delivery system 90 and the gas distribution device 62 deliver a plasma gas mixture including one or more gases to the processing chamber 70. A coil driving circuit 94 supplies RF power to the one or more inductive coils 64. During divergence measurement, one or more divergence sensors 98 are arranged on the surface 80 of the substrate support 74 in the processing chamber 70 (or in other locations within the processing chamber 70). A positioning device 100 may be used to adjust a position of the divergence sensors 98 relative to the surface 80 of the substrate support 74. The positioning device 100 may move the one or more ion beam divergence sensors 98 along an axial center line of the surface 80 and/or to any location on or above the surface 80.

[0039] A controller 96 may be used to control the positioning device 78, the positioning device 100, the substrate support 74, the coil driving circuit 94, the gas delivery system 90, and/or other components of the ion beam processing system 50.

[0040] During operation, the gas delivery system 90 and the gas distribution device 62 deliver the plasma gas mixture to the enclosure 61. The coil driving circuit 94 outputs RF power to the one or more inductive coils 64 to induce a magnetic field inside of the enclosure 61. The induced magnetic field strikes and maintains plasma 91 in the enclosure 61. The plasma 91 produces an ion beam 97 including ions. The ions of the ion beam 97 pass through the grid 66 and impact an exposed surface of the substrate 84 during etching or the ion beam divergence sensor 98 during divergence measurement.

[0041] Referring now to FIGs. 2A and 2B, examples of different ion beam divergence angles are shown. Ions produced by plasma 110 travel through a grid 112 including one or more platens 114, 116, and 118 with aligned apertures. The platens 114, 116, and 118 may be connected to different voltage or ground potentials such as first and second voltage potentials V_b , V_s , respectively, and/or a reference potential such as ground. In FIG. 2A, a concave meniscus creates low perveance corresponding to large divergence and grid impingement. In FIG. 2B, a slightly less concave meniscus creates moderate perveance corresponding to small divergence and minimal grid impingement.

[0042] Referring now to FIG. 3, an ion beam divergence sensor 150 is arranged in the processing chamber 70 and is configured to measure an ion beam divergence angle. The ion beam divergence sensor 150 includes an enclosure 158 including a first aperture 160. In some examples, the first aperture 160 of the enclosure 158 has a diameter d in a y -

axis plane in FIG. 3. A Faraday cup 164 is arranged inside the enclosure 158 and includes a second aperture 168. A Faraday cup is a metal (conductive) cup that is designed to catch charged particles in vacuum. The resulting current can be measured and used to determine the number of ions or electrons hitting the cup. In some examples, the second aperture 168 has a diameter d_1 in the y-axis in FIG. 3.

[0043] During measurement, a first positioning device 170 moves the Faraday cup 164 along the x-axis direction within the enclosure 158. An upper surface of the Faraday cup 164 is located a predetermined distance l from the upper surface of the enclosure 158. A second positioning device 174 moves the enclosure 158 and the Faraday cup 164 relative to a substrate support 175 to allow measurement at other locations. A current sensor 178 measures current output by the Faraday cup 164 in response to ions that are received.

[0044] Controllably changing the x-axis position of the Faraday cup 164 within the enclosure 158 during the divergence angle measurement increases the spatial resolution of the Faraday cup 164. In use, the second positioning device 174 moves the enclosure 158 to a desired location for measurement of divergence. Then the first positioning device 170 positions the Faraday cup 164 in an initial position within the enclosure 158 and the current output by the Faraday cup 164 is measured while ions are delivered. Then the first positioning device 170 moves the Faraday cup 164 to a plurality of other positions in the enclosure 158 and the current output by the Faraday cup 164 is measured at those locations. The measurements typically have a Gaussian distribution. If desired, the enclosure 158 is moved to one or more other positions on the substrate support 175 and the process is repeated to measure the divergence angle at those locations.

[0045] Referring now to FIG. 4, beam current is shown as a function of a position of the Faraday cup 164 (e.g., in an x-axis direction) relative to the enclosure 158. The relationship between ion current can be used to define ion beam width. For example, ion beam width may be defined by a predetermined percentage (e.g., 50%, 60%, 70%, 80%) of the maximum measured current. In some examples, the ion beam width is defined by full width at half maximum (FWHM) or other criteria. In a distribution, FWHM corresponds to the difference between the two values of the independent variable at which the

dependent variable is equal to half of its maximum value. In some examples, the divergence angle is equal to:

$$\Theta = \arctan((\text{beam diameter}-d)/(2 * l)).$$

[0046] Referring now to FIG. 5, calculated ion current is shown as a function of a position of the Faraday cup at various lateral positions within the enclosure 158. Calculated ion current is shown for 2°, 4°, 6°, and 8°.

[0047] Referring now to FIG. 6, an ion beam divergence sensor 180 is arranged in the processing chamber 70 and is configured to measure the ion beam divergence angle. The ion beam divergence sensor 180 includes the enclosure 158 with the first aperture 160. The Faraday cup 164 is arranged in the enclosure 158 and includes the second aperture 168. In some examples, the first aperture 160 and the second aperture 168 are aligned relative to a line parallel to the y-axis.

[0048] A first positioning device 190 moves the Faraday cup 164 in the y-axis direction within the enclosure 158 to vary the predetermined distance *l*. The second positioning device 174 moves the enclosure 158 and the Faraday cup 164 relative to the substrate support.

[0049] In use, the second positioning device 174 moves the enclosure 158 to a desired location relative to the substrate support for measurement of the divergence angle. Then the first positioning device 170 positions the Faraday cup 164 in an initial vertical position *y* on the y-axis in the enclosure 158 and the current output by the Faraday cup 164 is measured while ions are supplied. Then, the first positioning device 170 positions the Faraday cup 164 in a plurality of other vertical positions of *y* along the y-axis within the enclosure 158 and the current output by the Faraday cup 164 is measured for each position.

[0050] Referring now to FIGs. 7 and 8, graphs of ion beam current and calculated ion current are shown. In FIG. 7, ion beam current is shown for various vertical positions *y* of the Faraday cup 164 within the enclosure 158 along the y-axis (for a given position of the enclosure 158). In FIG. 8, the distance *l* between the first aperture of the enclosure 158 and the second aperture of the Faraday cup 164 is varied during testing to determine the divergence angle Θ .

[0051] The divergence angle Θ causes the ion current to be different for different values of y . The divergence angle Θ is calculated by fitting current I as a function of position y (or $I(y)$):

$$I(y) = \int_{-\frac{d}{2}}^{\frac{d}{2}} \frac{A}{r(y)} \exp\left(\frac{-2x^2}{r(y)^2}\right) dx = \text{Berf}\left(\frac{d}{\sqrt{2}r(y)}\right)$$

$$l = \frac{d-d_1}{2\tan\Theta}; \text{ and}$$

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$$r(y)=y\tan\Theta.$$

[0052] In FIG. 9, calculated ion current is shown as a function of a vertical position of the Faraday cup within the enclosure 158. Calculated ion current is shown for 2° , 4° , 6° , and 8° .

[0053] Referring now to FIGs. 10A and 10B, an ion beam divergence sensor 240 includes an enclosure 252 with an aperture 254. The enclosure 252 defines separate measurement regions 264-1, 264-2, ..., and 264-6 (collectively or individually measurement regions 264). An array of current sensors 270-1, 270-2, 270-3, ..., and 270-6 (collectively or individually current sensors 270) measures current corresponding to ion bombardment in the measurement regions 264.

[0054] More particularly, the enclosure 252 includes projections 260-1, 260-2, 260-3, 260-4 and 260-5 (collectively or individually projections 260) that extend inwardly from one or more side surfaces of the enclosure 252 to isolate the measurement regions 264 within the enclosure 252. In some examples, the projections 260 are annular and extend around the one or more side surfaces or on a bottom surface. The projections 260-1, 260-2, and 260-3 extend in a horizontal plane and are stacked in a spaced arrangement vertically along the one or more side surfaces of the enclosure 252. In FIG. 10B, projections 260-4 and 260-5 are shown arranged concentrically on a bottom surface of the enclosure 252. Since the ion beam is typically symmetric for a given measurement, measurements may be made on one or both sides of the enclosure 252.

[0055] Current sensors 270 measure current levels at respective locations between adjacent ones of the projections 260. If the ion beam is symmetric, the current sensors 270 can sense current on one side of the enclosure 252 rather than both sides.

[0056] Referring now to FIGs. 11A to 12, another example of a divergence measurement system 300 is shown. A capillary plate 310 includes a channel 312 that extends through a body of the capillary plate 310. The diameter of the channel 312 and the length of the body define an aspect ratio (AR) of the capillary plate 310. For example, a capillary plate with an ER in a range from 10: to 100:1 (e.g., a 57:1 AR may be used for 1° of resolution).

[0057] The capillary plate 310 is arranged adjacent to a Faraday cup 320 having an aperture 322 aligned with the channel 312 of the capillary plate 310. The capillary plate 310 and the Faraday cup 320 are arranged on a substrate support 330. In some examples, the substrate support 330 is tilted to one or more angles (e.g., 2°, 4°, 6°, 8°, etc. as shown in FIGs. 11B and 11C) and current is measured while ions are delivered to determine the divergence angle Θ .

[0058] In FIG. 12, a tilt axis of the substrate support 330 is shown. The capillary plate 310 and the Faraday cup 320 are arranged at a desired location of the substrate support 330. The tilt axis of the substrate support 330 is adjusted to one or more tilt angles and current measurements are made at the one or more tilt angles using the capillary plate 310 and the Faraday cup 320. The capillary plate 310 and the Faraday cup 320 can be moved to other locations for additional measurements if desired.

[0059] In FIG. 13, a tilt adjustment device 350 can be arranged between the capillary plate 310 and the Faraday cup 320 and the substrate support 330 to adjust the tilt of the capillary plate 310 and the Faraday cup 320 relative to the substrate support 330 (rather than adjusting tilt using the substrate support).

[0060] Referring now to FIG. 14, a platen 410 includes a plurality of ion beam divergence sensors 420 arranged at a plurality of locations for ion beam divergence measurement. This arrangement allows ion beam divergence angles to be measured in parallel to reduce testing time and increase productivity.

[0061] The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the

present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

[0062] Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including “connected,” “engaged,” “coupled,” “adjacent,” “next to,” “on top of,” “above,” “below,” and “disposed.” Unless explicitly described as being “direct,” when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean “at least one of A, at least one of B, and at least one of C.”

[0063] In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, including a processing tool or tools, chamber or chambers, a platform, or platforms for processing, and/or specific processing components (a wafer pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

[0064] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of
5 firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a
10 particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0065] The controller, in some implementations, may be a part of or coupled to a
15 computer that is integrated with the system, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication
20 operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g., a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface
25 that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type
30 of tool that the controller is configured to interface with or control. Thus, as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in

communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

5 [0066] Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or
10 module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0067] As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules,
15 other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

CLAIMS

What is claimed is:

1. A divergence measurement system, comprising:
an ion beam sensor including:
5 an enclosure including a first aperture on a first surface of the enclosure;
and
a Faraday cup arranged in the enclosure and including a second aperture
configured to receive ions generated by a plasma source and configured to generate a
current signal based thereon; and
10 a first positioning device configured to move the Faraday cup within the
enclosure.
2. The divergence measurement system of claim 1, wherein the first positioning
device is configured to move the Faraday cup within the enclosure in a plane that is
parallel to the first surface of the enclosure including the first aperture.
- 15 3. The divergence measurement system of claim 2, further comprising:
a current sensor configured to sense the current signal; and
a controller configured to receive the current signal from the current sensor and to
calculate a divergence angle based thereon.
4. The divergence measurement system of claim 3, wherein the controller is
20 configured to calculate a beam diameter for a predetermined location based on a
predetermined percentage of a maximum current value measured by the current sensor
and to calculate the divergence angle based on the beam diameter.
5. The divergence measurement system of claim 2, further comprising a second
positioning device configured adjust a position of the enclosure and the Faraday cup
25 relative to a substrate support of a processing chamber.
6. The divergence measurement system of claim 1, wherein the first positioning
device is configured to move the Faraday cup within the enclosure in a plane that is
transverse to the first surface of the enclosure including the first aperture.

7. The divergence measurement system of claim 6, further comprising:
a current sensor configured to sense the current signal; and
a controller configured to receive the current signal from the current sensor and to calculate a divergence angle based thereon.
- 5 8. The divergence measurement system of claim 6, further comprising a second positioning device configured adjust a position of the enclosure and the Faraday cup relative to a substrate support of a processing chamber.
9. The divergence measurement system of claim 1, further comprising:
a platen; and
10 M of the ion beam sensor arranged on the platen.
10. A divergence measurement system, comprising:
an ion beam sensor including:
an enclosure including one or more side walls, a first surface, and a second surface including an aperture;
15 a plurality of annular projections extending inwardly into the enclosure from at least one of the side walls and the first surface to define a plurality of measurement regions in the enclosure; and
a plurality of current sensors configured to measure current in at least two of the plurality of measurement regions.
- 20 11. The divergence measurement system of claim 10, further comprising a positioning device configured adjust a position of the enclosure relative to a substrate support of a processing chamber.
12. The divergence measurement system of claim 10, wherein the plurality of annular projections includes a first annular projection arranged on the first surface and a second
25 annular projection arranged on the first surface within the first annular projection.
13. The divergence measurement system of claim 10, wherein the plurality of annular projections includes a first annular projection arranged on the one or more side walls and a second annular projection arranged on the one or more side walls spaced from the first annular projection.

14. The divergence measurement system of claim 10, further comprising a controller configured to receive current signals from the plurality of current sensors and to calculate a divergence angle based thereon.

15. The divergence measurement system of claim 14, wherein the controller is configured to calculate a beam diameter for a predetermined location based on a predetermined percentage of a maximum current value measured by the plurality of current sensors and to calculate the divergence angle based on the beam diameter.

16. A divergence measurement system for a processing chamber receiving an ion beam from a plasma source, comprising:

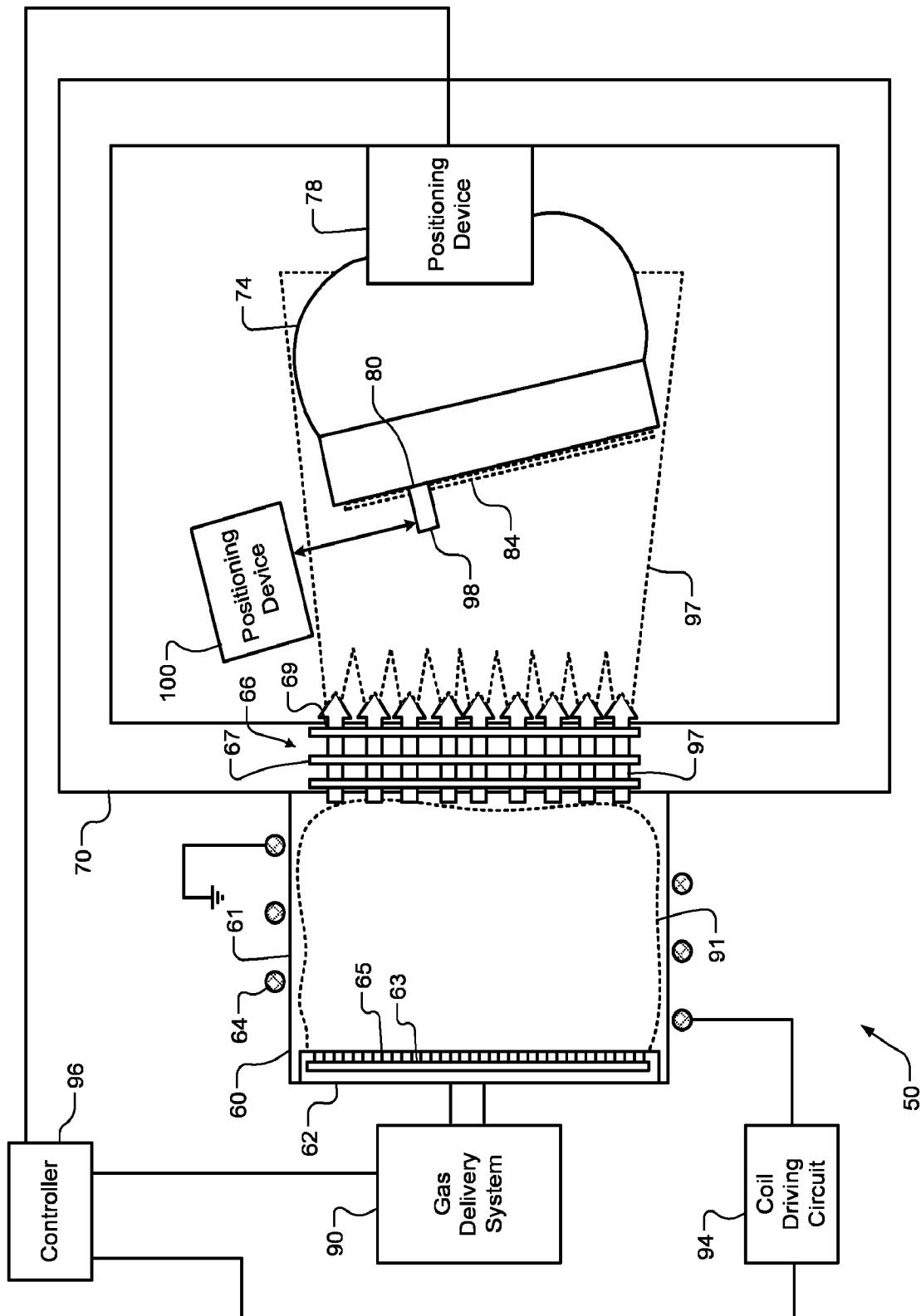
an ion beam sensor including:
a capillary plate including a channel;
a Faraday cup connected to the capillary plate and including an aperture aligned with the channel of the capillary plate,
wherein the Faraday cup is configured to receive ions generated by the plasma source and to generate a current signal based thereon; and
a tilt adjusting device configured to adjust a tilt angle of the capillary plate and the Faraday cup to a plurality of tilt angles.

17. The divergence measurement system of claim 16, further comprising a positioning device configured adjust a position of the ion beam sensor relative to a substrate support in the processing chamber.

18. The divergence measurement system of claim 16, further comprising:
a current sensor configured to sense the current signal; and
a controller configured to receive the current signal at the plurality of tilt angles and to calculate a divergence angle based thereon.

19. The divergence measurement system of claim 18, wherein the controller is configured to calculate a beam diameter for a predetermined location based on a predetermined percentage of a maximum current value measured at the plurality of tilt angles and to calculate the divergence angle based on the beam diameter.

20. The divergence measurement system of claim 16, wherein the tilt adjusting device is configured to adjust a tilt angle of substrate support to adjust the tilt angle of the capillary plate and the Faraday cup.



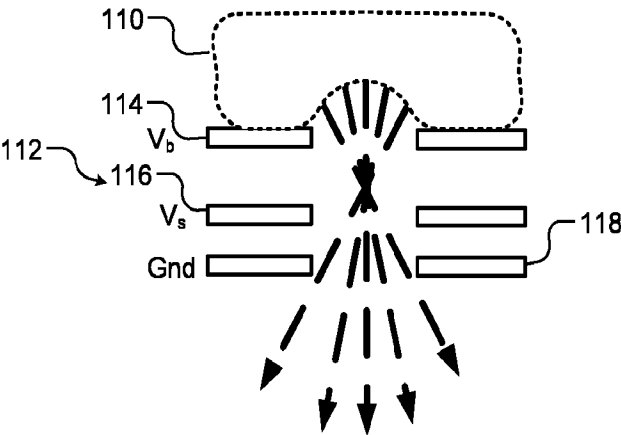


FIG. 2A

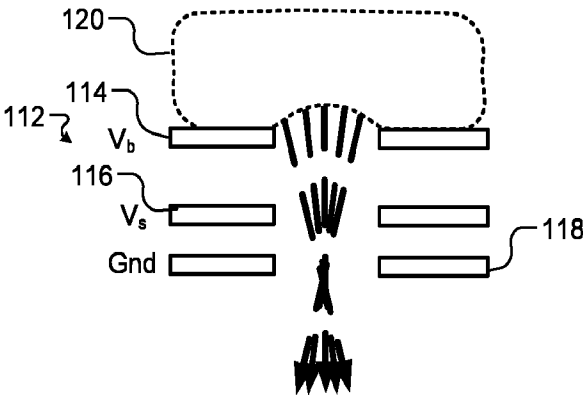
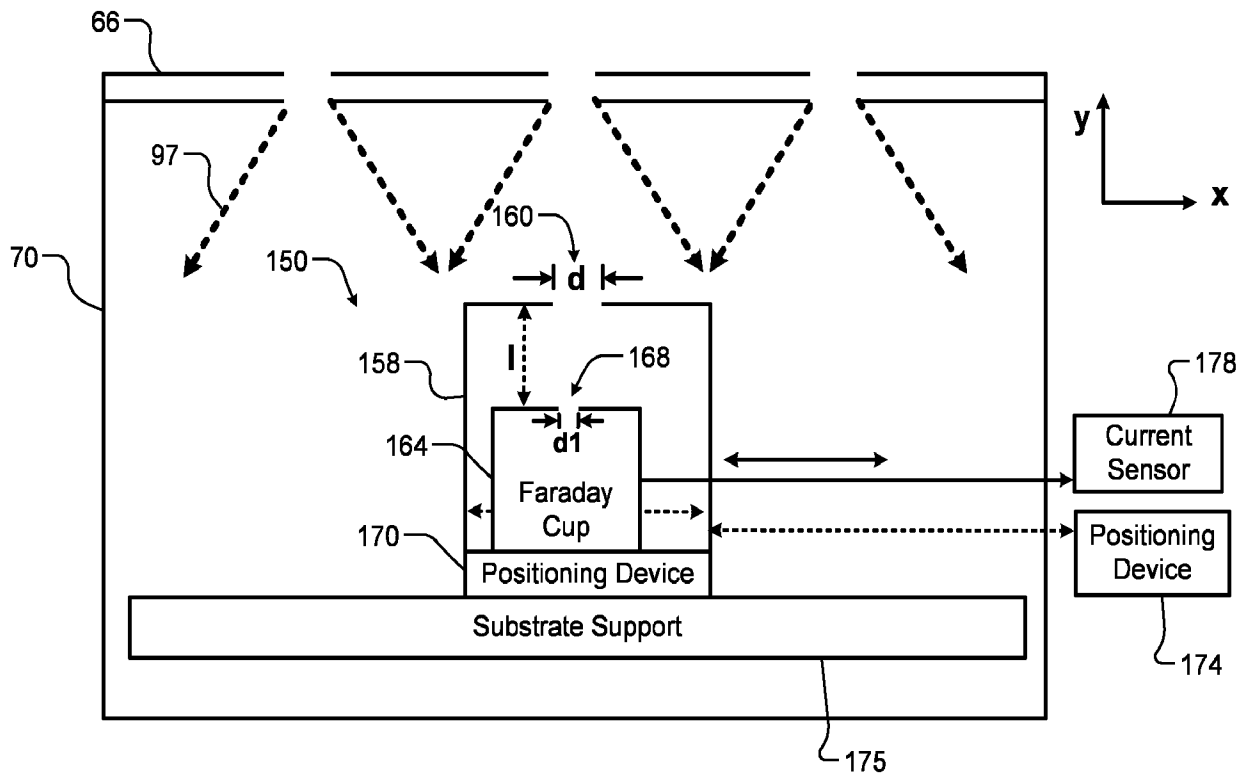
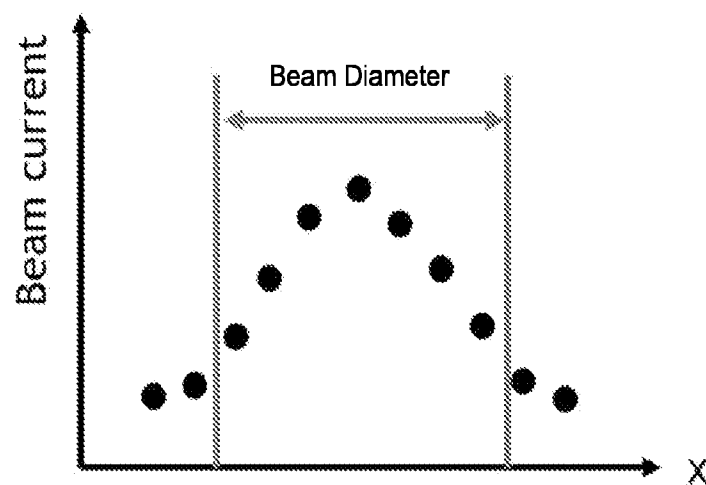


FIG. 2B

**FIG. 3****FIG. 4**

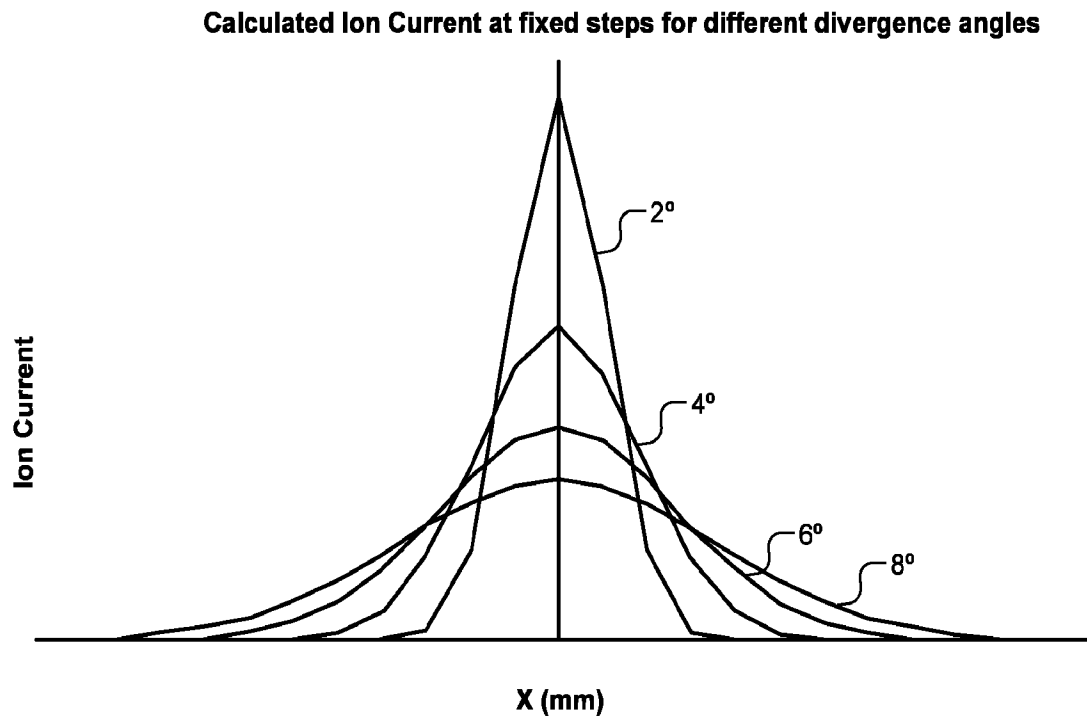


FIG. 5

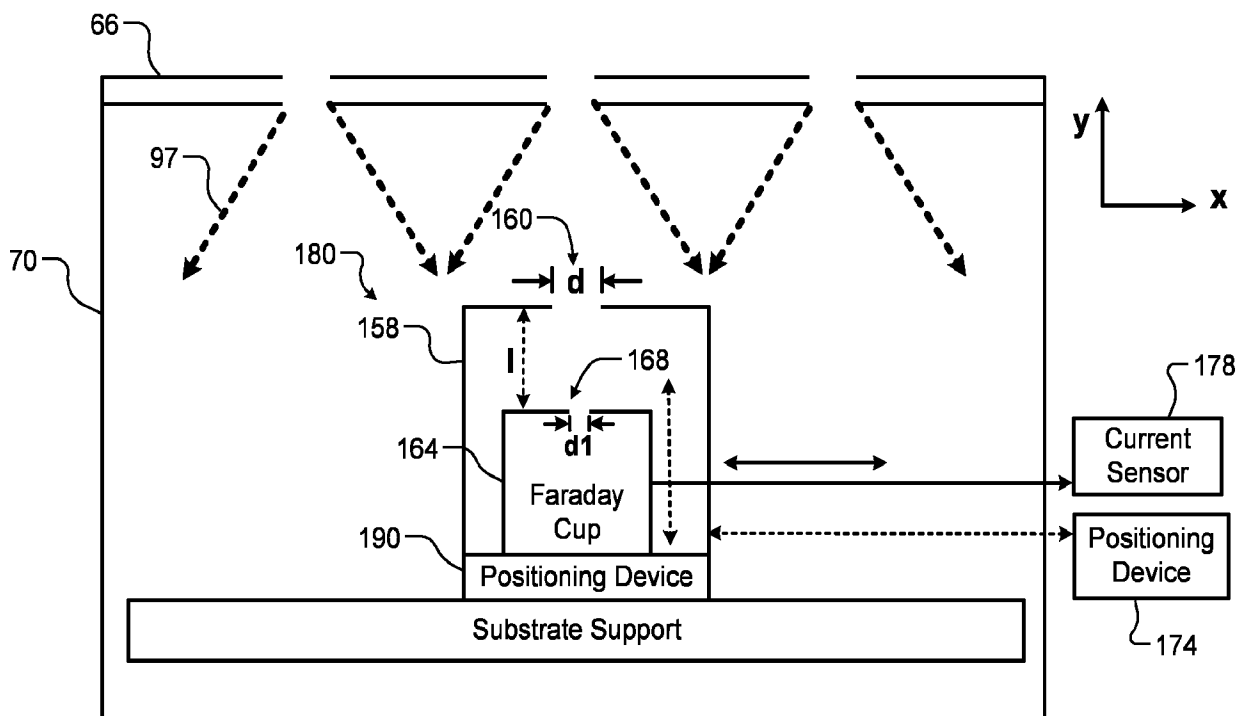


FIG. 6

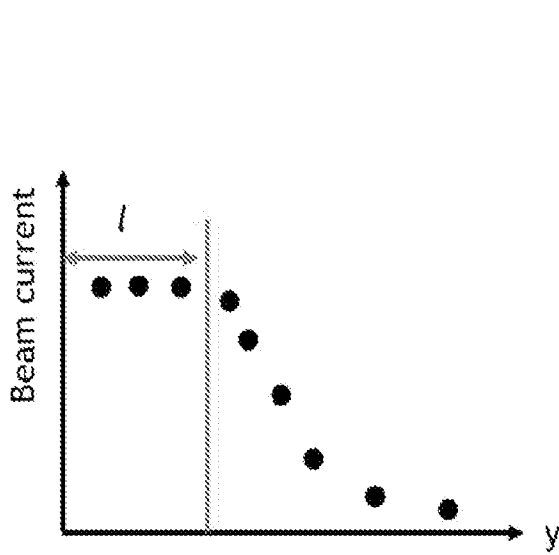


FIG. 7

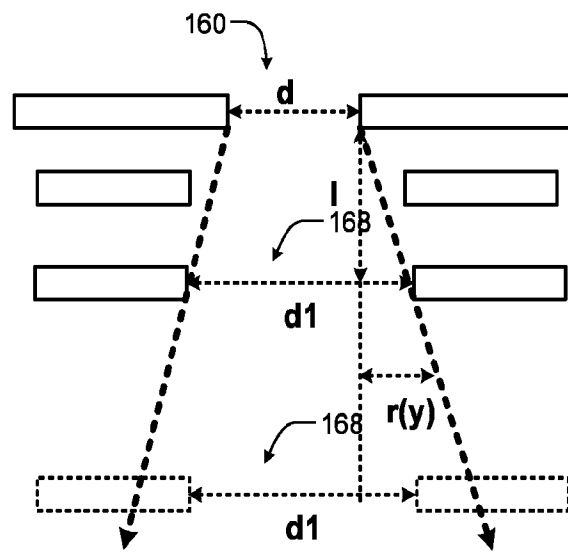


FIG. 8

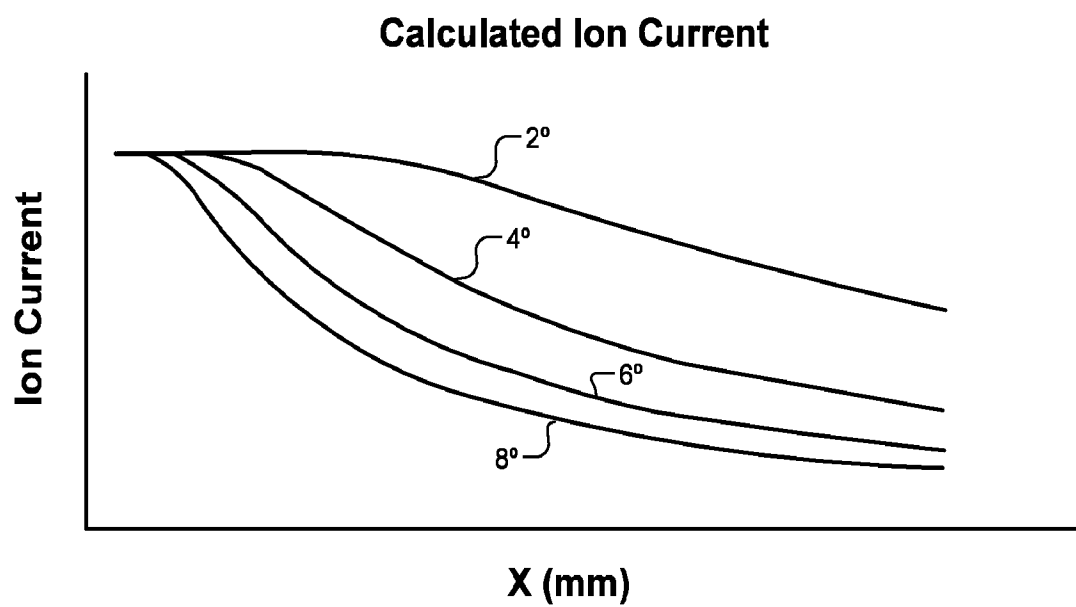


FIG. 9

FIG. 10A

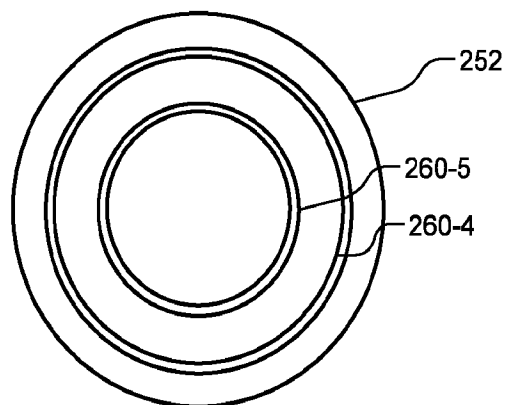
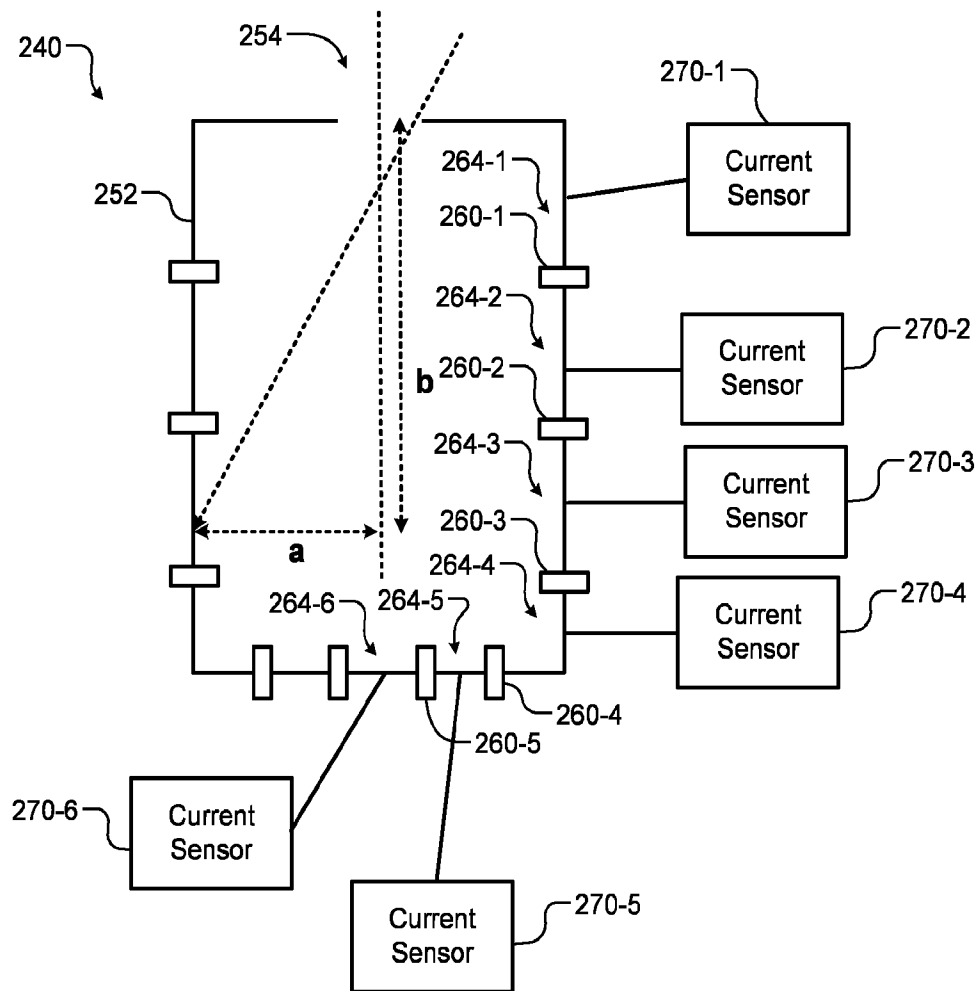


FIG. 10B

FIG. 11A

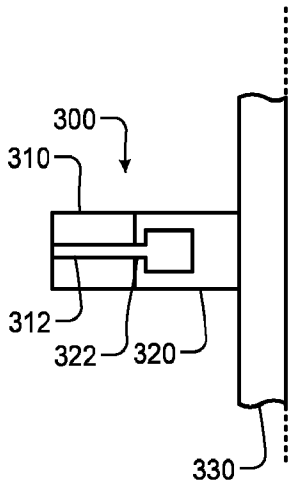


FIG. 11B

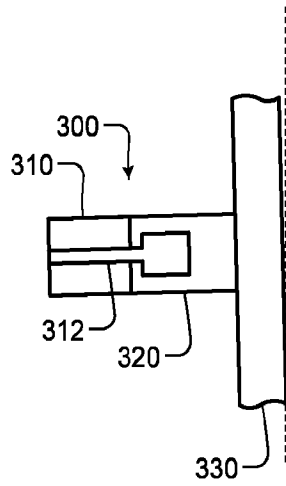


FIG. 11C

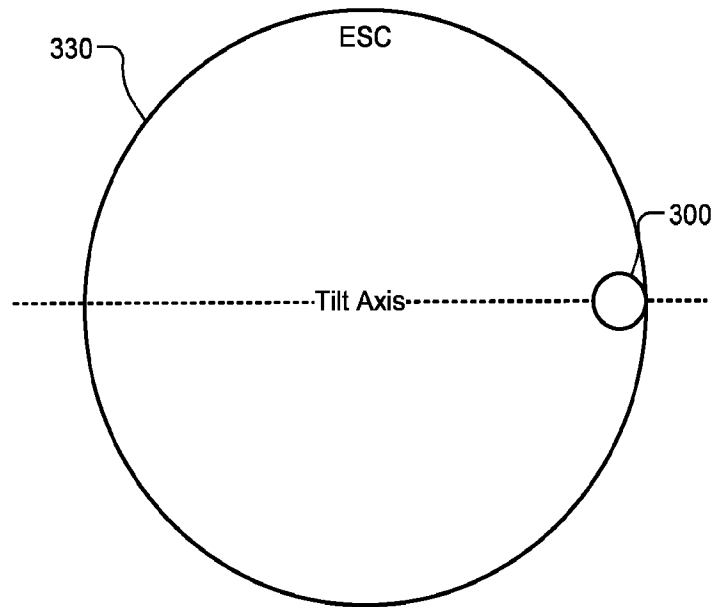
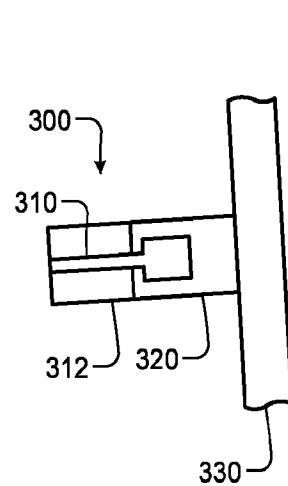
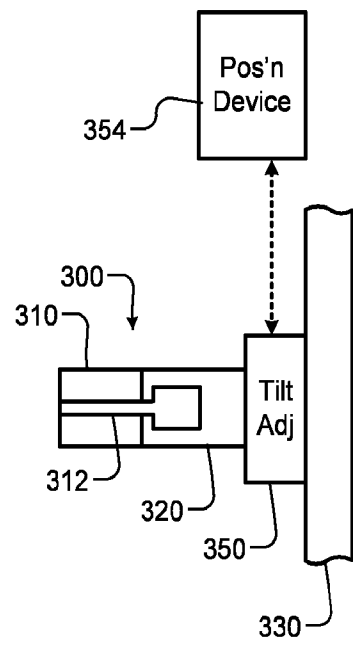
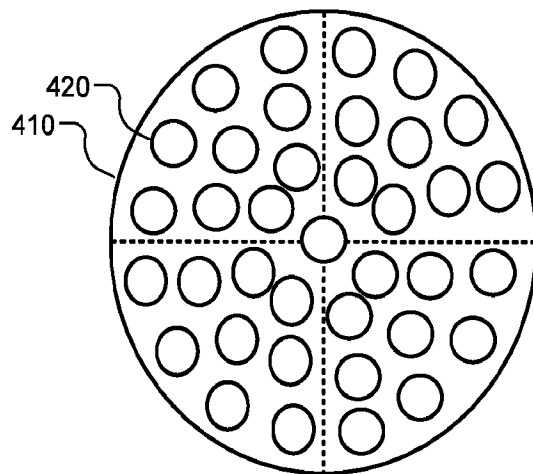


FIG. 12

**FIG. 13****FIG. 14**