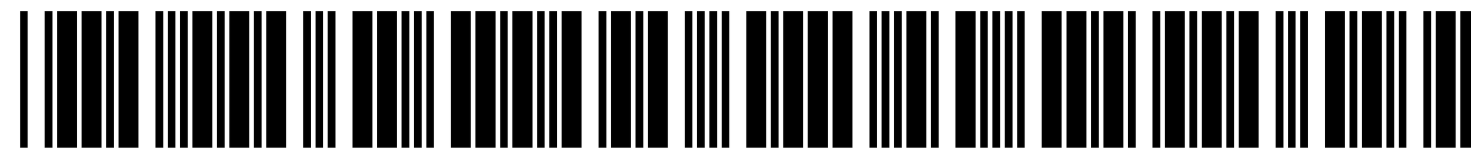

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(54) **PLASMA CONFINEMENT BY USE OF PREFERRED RF RETURN PATH**

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Related U.S. Patent Documents

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C23C 16/00 (2006.01)

(52) **U.S. Cl.** .... **156/345.43**; 216/67; 118/723 E

(58) **Field of Classification Search** .... 156/345.43, 156/345.47; 118/715, 722, 723 R, 723 E; 438/706, 707, 710; 216/63, 67
See application file for complete search history.

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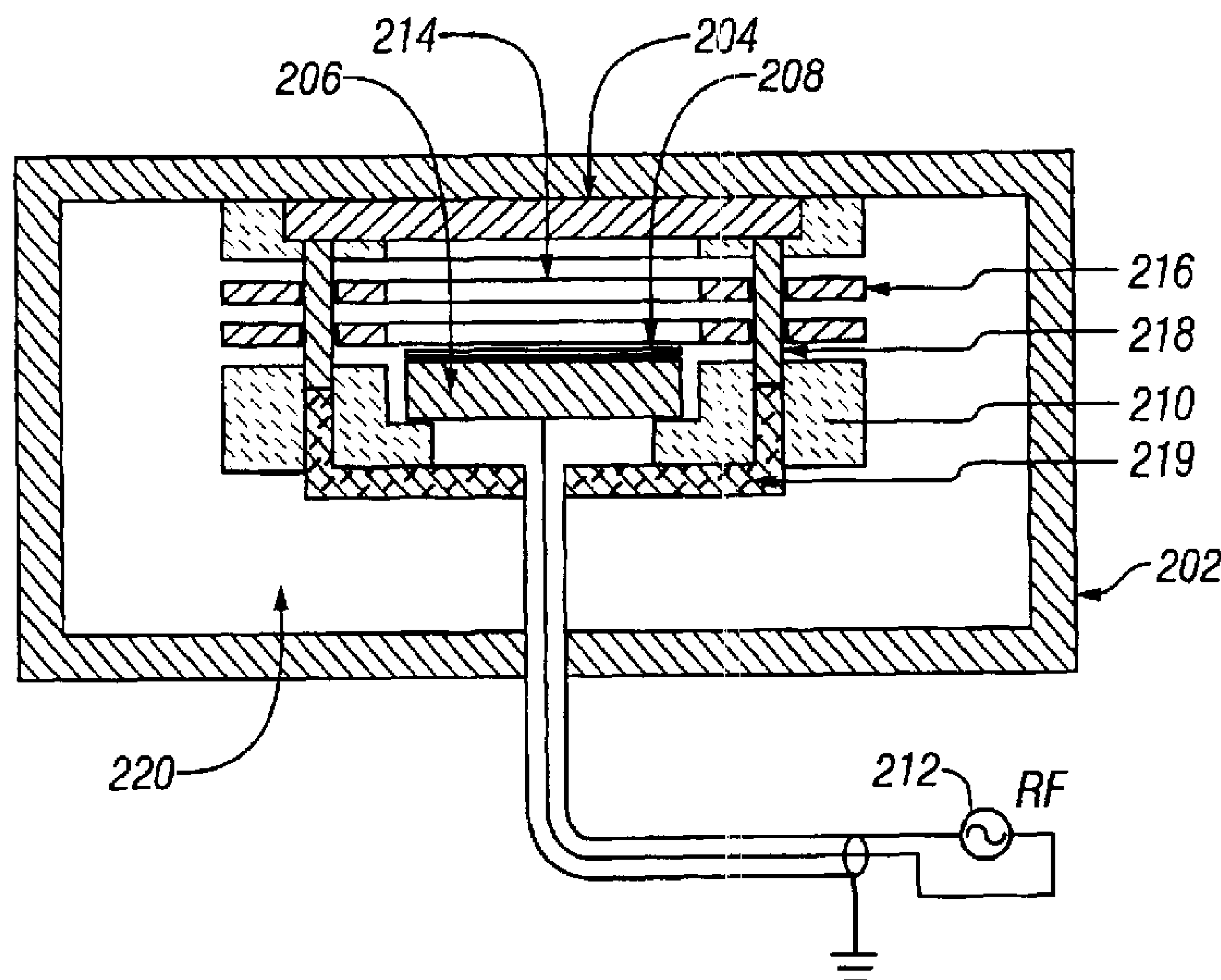
(57) **ABSTRACT**

A confinement assembly for confining a discharge within an interaction space of a plasma processing apparatus comprising a stack of rings and at least one electrically conductive member. The rings are spaced apart from each other to form slots therebetween and are positioned to surround the interaction space. At least one electrically conductive member electrically couples each ring. The electrically conductive member contacts each ring at least at a point inside of the outer circumference of each ring.

19 Claims, 3 Drawing Sheets



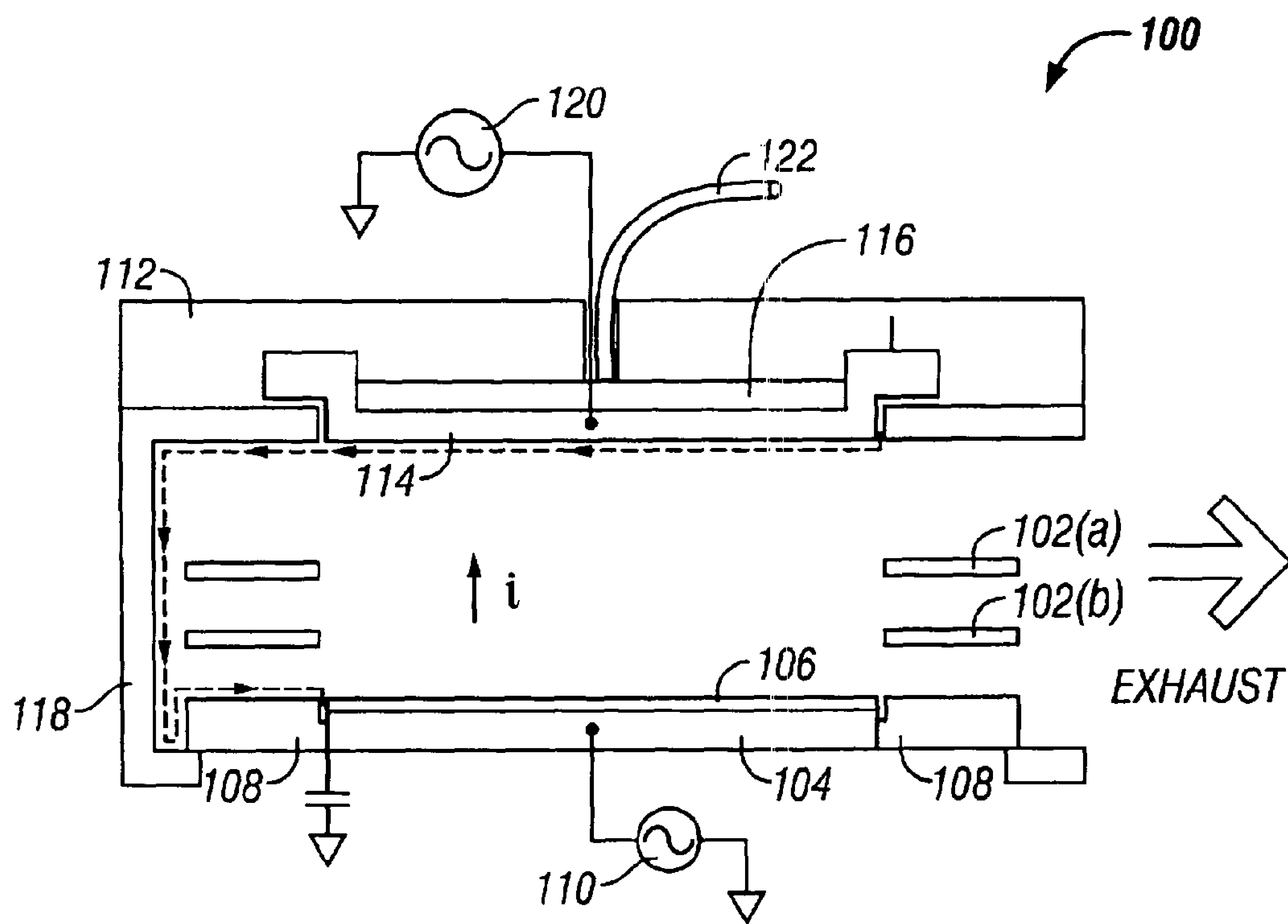


FIG. 1A
(Prior Art)

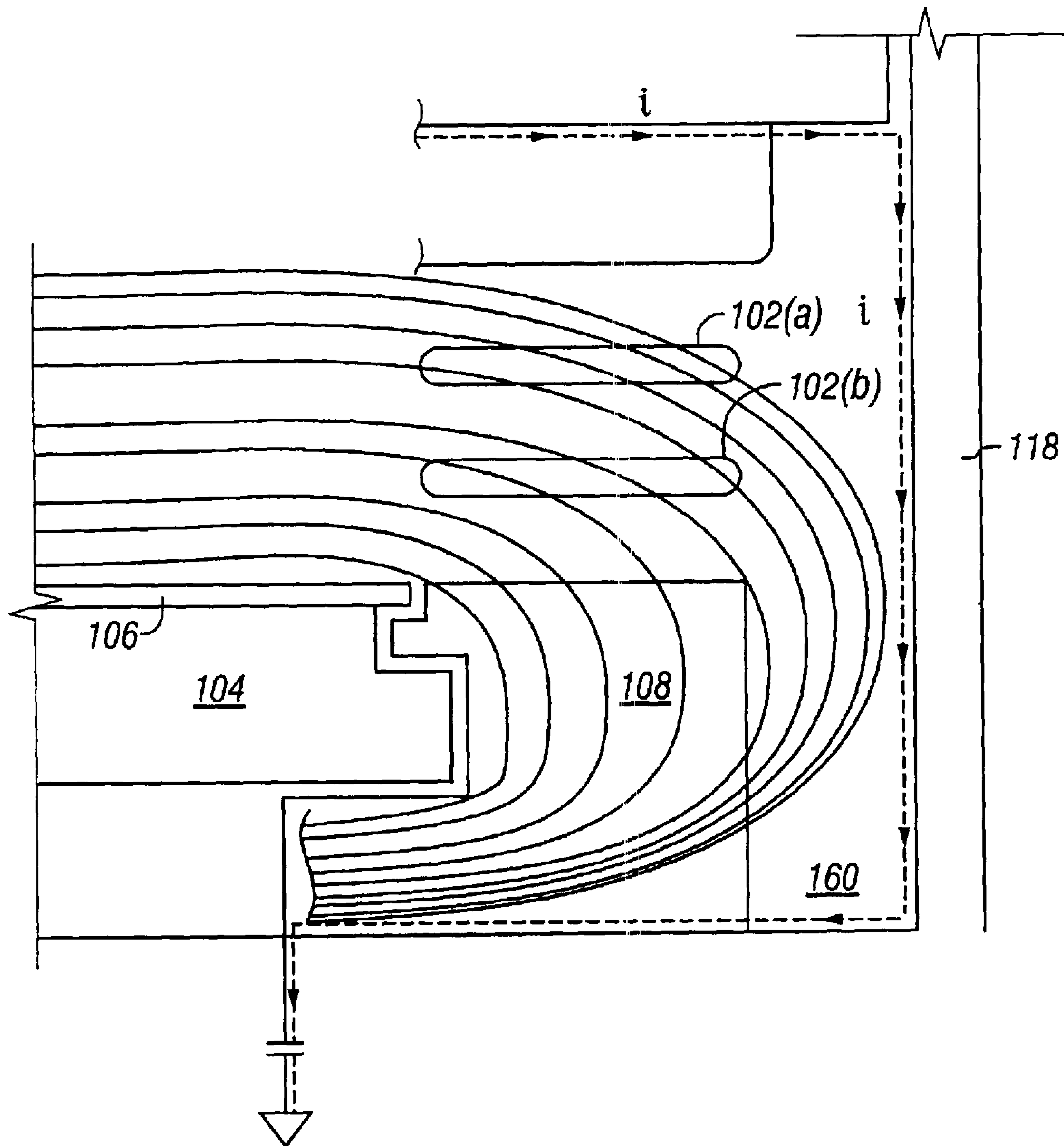


FIG. 1B
(Prior Art)

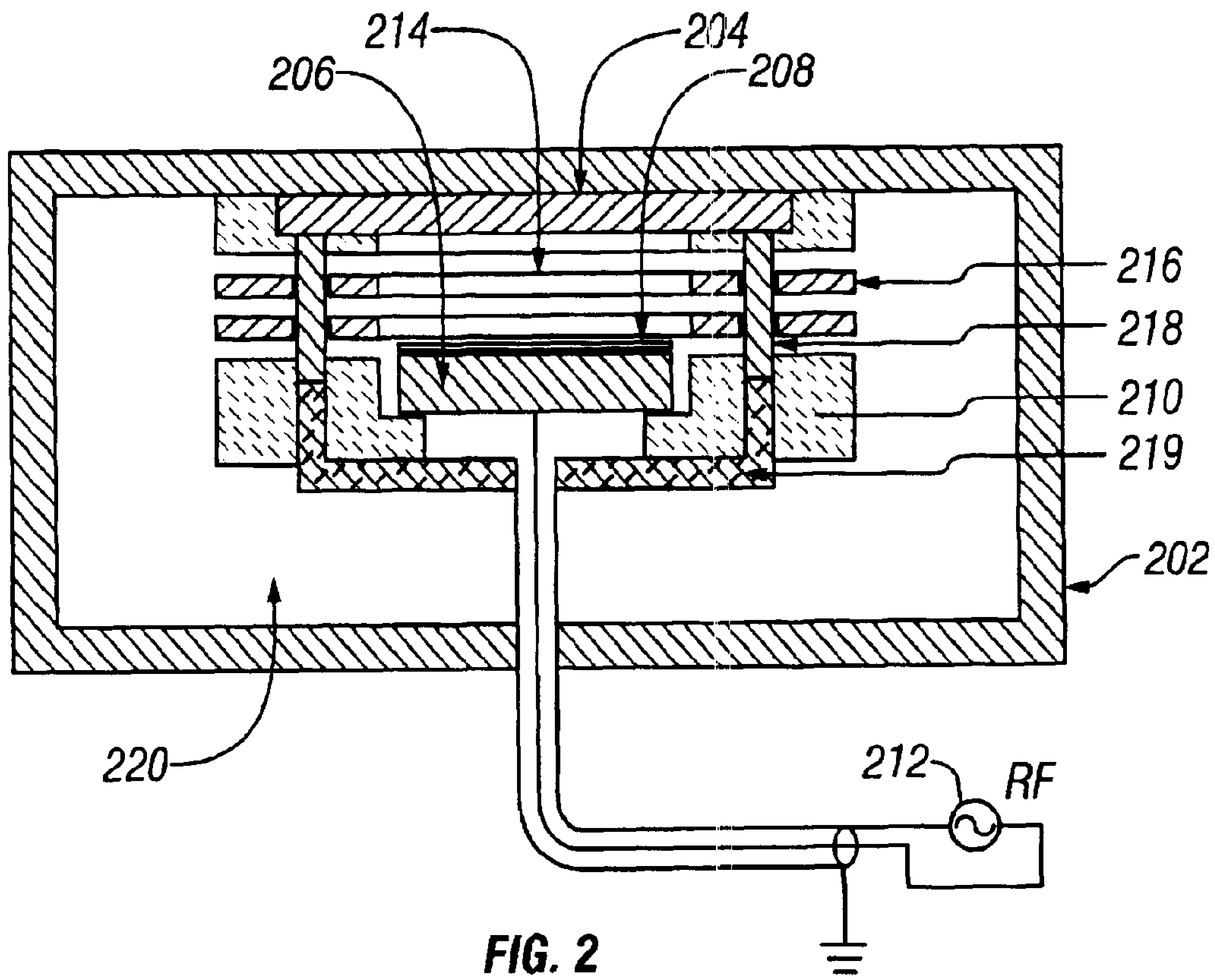


FIG. 2

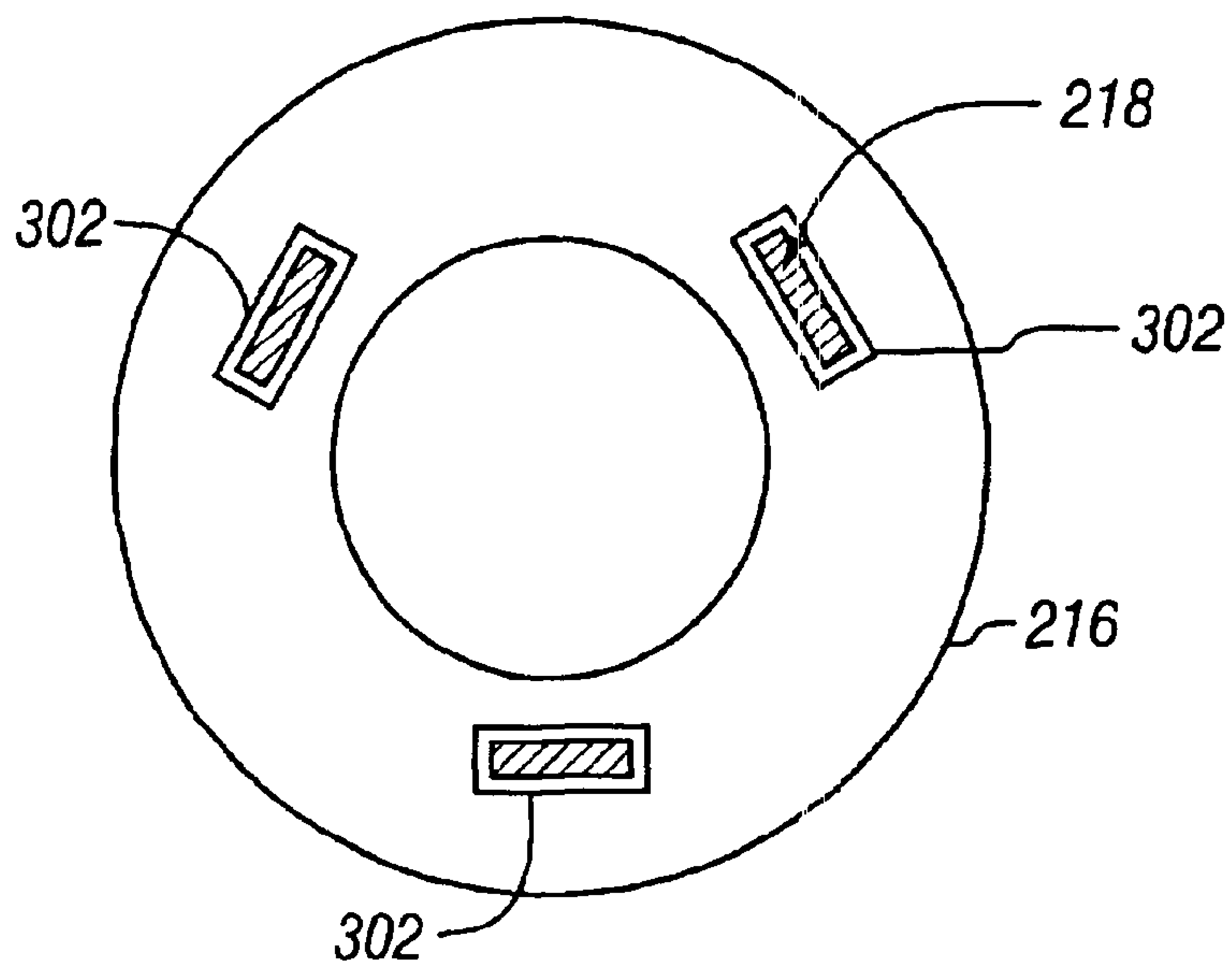


FIG. 3

PLASMA CONFINEMENT BY USE OF PREFERRED RF RETURN PATH

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

More than one reissue application has been filed for the reissue of U.S. Pat. No. 6,602,381. The reissue applications are Ser. No. 11/196,842 (the present application), Ser. Nos. 12/078,349 and 12/078,348, both of which are divisional reissues of U.S. Pat. No. 6,602,381. Because all claims of the divisional applications have been indicated as allowable over the prior art and the PTO has advised that the claims of the divisional applications should be merged with the claims of the originally filed reissue application, such a merger is being performed and the divisional applications are being abandoned.

FIELD OF THE INVENTION

The present invention relates to plasma etching apparatus. More particularly, the present invention relates to improved techniques for controlling plasma formation in a plasma processing chamber.

BACKGROUND OF THE INVENTION

The use of plasma-enhanced processes in the manufacture of semiconductor-based products (such as integrated circuits or flat panel displays) is well known. Generally speaking, plasma-enhanced processes involve the processing of a substrate (e.g., a glass panel or a semiconductor wafer) in a plasma processing chamber. Within the plasma processing chamber, a plasma may be formed out of appropriate etchant or deposition source gases to respectively etch or deposit a layer of material on the surface of the substrate.

FIG. **1** depicts a capacitively-coupled plasma processing chamber **100**, representing an exemplary plasma processing chamber of the types typically employed to etch a substrate. A chuck **104** represents the workpiece holder on which a substrate **106** is positioned during etching. The chuck **104** may be implemented by any suitable chucking technique, e.g., electrostatic, mechanical, clamping, vacuum, or the like. During etching, the chuck **104** is typically supplied with RF power having a frequency of, for example, about 400 Khz to about 27 Mhz, by an RF power supply **110**. In some systems, chuck **104** may be supplied with dual frequencies, e.g., 2 MHz and 27 MHz simultaneously during etching.

A reactor top **112**, formed of a conductive material such as aluminum, is disposed above substrate **106**. Confinement rings **102** may be coupled in a fixed manner to reactor top **112** or may be coupled to cam-based plungers (not shown in FIG. **1**) that allow confinement rings **102** to be raised and lowered without moving reactor top **112**.

In general, confinement rings **102** help confine the etching plasma to the region above substrate **106** to improve process control and to ensure repeatability. Although only two confinement rings are shown in the example of FIG. **1**, it should be understood that any number of confinement rings may be provided.

An upper electrode **114** and a baffle **116** are also coupled to reactor top **112**. The upper electrode **114** may be grounded (as in the case of FIG. **1**) or may be powered by another RF power source **120** during etching. If the upper electrode **114** is powered, it may be insulated from the remainder of the reactor to isolate the electrode from ground. During etching, plasma is formed from etchant[so]urce gas supplied via a gas line **122** and the baffle **116**.

When RF power is supplied to the chuck **104** (from the radio frequency generator **110**), equipotential field lines are set up over the substrate **106**. During plasma processing, the positive ions accelerate across the equipotential field lines to impinge on the surface of substrate **106**, thereby providing the desired etch effect (such as improving etch directionality). Due to geometry factors, however, the field lines may not be uniform across the substrate surface and may vary significantly at the edge of substrate **106**. Accordingly, a focus ring is typically provided to improve process uniformity across the entire substrate surface. With reference to FIG. **1**, chuck **104** is shown disposed within a focus ring **108**, which is typically formed of a suitable dielectric material such as ceramic, quartz, or plastic.

The equipotential field lines that are set up during plasma etching may be seen more clearly in FIG. **1**B. In FIG. **1**B, the presence of focus ring **108** allows the equipotential field lines to be disposed substantially uniformly over the entire surface of the substrate, thereby allowing etching to proceed in a uniform manner across the substrate. As seen by FIG. **2**, however, some of the equipotential field lines also extend into the region **160** outside of focus ring **108**. The presence of the equipotential field lines in region **160** may cause any charged particles that leak past the confinement rings to accelerate in a direction perpendicular to the equipotential field lines toward the chamber walls. This acceleration and the subsequent collision between the charged particles and the chamber walls may generate secondary electrons, which may ignite and/or sustain unconfined plasma in the region **160** (i.e., unintended plasma that is not confined to region directly above the substrate).

Furthermore, current return paths have relied on the chamber wall **118** for a return path or a return path outside the chamber. Magnetic fields are generated from the return paths and cause magnetic fields that can light and sustain a plasma outside the confined region. The dotted lines in FIGS. **1**A and **1**B illustrate the current return path along the chamber wall **118**.

The inadvertent generation of plasma in the region **160** renders the etch process difficult to control and may damage components within this region. By way of example, this unconfined plasma, which may be unplanned and/or intermittent, changes the location of power absorbed by the plasma within the plasma processing chamber, thereby making it difficult to control the delivery of power to the chuck to achieve consistent, repeatable etch results. As another example, the presence of unwanted plasma in region **160** may cause damage to the chamber door (not shown), particularly to the seals that are provided therewith. The chamber door is necessary for substrate transport into and out of the chamber, and if the seals are damaged, accurate control of the chamber pressure may be difficult. When the seals and/or other components in the region **160** are inadvertently attacked by the plasma, particulate and/or polymeric contaminants may form along the chamber walls, potentially leading to contamination of the etch environment.

Accordingly, it would be desirable to provide techniques for minimizing and/or eliminating the unwanted plasma formation in the region outside of the focus ring of the plasma processing chamber.

BRIEF DESCRIPTION OF THE INVENTION

A confinement assembly for confining a discharge within an interaction space of a plasma processing apparatus com-

prising a stack of rings and at least one electrically conductive member. The rings are spaced apart from each other to form slots therebetween and are positioned to surround the interaction space. At least one electrically conductive member electrically couples each ring. The electrically conductive member contacts each ring at least at a point inside of the outer circumference of each ring.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and constitute a part of this specification, illustrate one or more embodiments of the present invention and, together with the detailed description, serve to explain the principles and implementations of the invention.

In the drawings:

FIG. **1**A is schematic diagram illustrating a typical capacitively coupled plasma processing chamber in accordance with the prior art;

FIG. **1**B a schematic diagram illustrating the equipotential field lines that may be formed in the plasma processing chamber of FIG. **1**A during plasma processing in accordance with the prior art;

FIG. **2** is a schematic cross-sectional diagram of a capacitively coupled plasma processing chamber having a preferred return path in accordance with a specific embodiment of the present invention; and

FIG. **3** illustrates a top view of a confinement ring having a preferred return path in accordance with a specific embodiment of the present invention.

DETAILED DESCRIPTION

Embodiments of the present invention are described herein in the context of controlling plasma formation in a plasma processing chamber. Those of ordinary skill in the art will realize that the following detailed description of the present invention is illustrative only and is not intended to be in any way limiting. Other embodiments of the present invention will readily suggest themselves to such skilled persons having the benefit of this disclosure. Reference will now be made in detail to implementations of the present invention as illustrated in the accompanying drawings. The same reference indicators will be used throughout the drawings and the following detailed description to refer to the same or like parts.

In the interest of clarity, not all of the routine features of the implementations described herein are shown and described. It will, of course, be appreciated that in the development of any such actual implementation, numerous implementation-specific decisions must be made in order to achieve the developer's specific goals, such as compliance with application- and business-related constraints, and that these specific goals will vary from one implementation to another and from one developer to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking of engineering for those of ordinary skill in the art having the benefit of this disclosure.

In accordance with one aspect of the present invention, process control is substantially improved by reducing or eliminating the unconfined plasma (i.e., the unwanted plasma that is inadvertently ignited and/or sustained outside of the focus ring and the walls of the plasma chamber). Confinement rings consists of a stack of rings spaced apart from each other to form slots therebetween and positioned to surround the interaction space. During operation of the plasma processing apparatus, the distance an exiting charged particle must travel in the slot is substantially longer than its mean free path. As the term is employed herein, the region outside of the focus ring refers to annular region of the plasma processing chamber which is external to the column of space whose outer periphery is defined by the circumference of the focus ring. The plasma is preferably confirmed within this column of space. Outside of the focus ring, the electric field is preferably reduced to the point where plasma can no longer be sustained. By eliminating the unconfined plasma, the amount of power absorbed by the etching plasma that is disposed above the substrate may be more consistent from substrate to substrate, thereby rendering the etch repeatable. The elimination of the unconfined plasma also helps reduce the corrosion or break down of components disposed in the region outside of the focus ring (e.g., door seals).

In accordance with one embodiment of the present invention, there is provided a confinement assembly, including a stack of focus rings configured to concentrate the equipotential field lines in the focus ring body. The focus rings preferably include at least one cavity disposed evenly around each ring and a corresponding number of electrically conductive members for returning the current to the ground. Each cavity receives and accommodates one member. It is believed that this configuration substantially reduces the density of equipotential field lines in the region outside of the focus ring. By substantially reducing the density of equipotential field lines in the near-vacuum region outside of the focus ring, the amount of energy acquired by any charged particle that leaks into this area is substantially reduced, thereby essentially eliminating the possibility of plasma formation and/or sustenance in this region.

The features and advantages of the present invention may be better understood with reference to FIGS. **2** and **3**. FIG. **2** is a schematic cross-sectional diagram of a capacitively coupled plasma processing chamber having a preferred return path according to a specific embodiment of the present invention. A plasma chamber **202** comprises an upper electrode **204** and a lower electrode **206** on which a workpiece **208**, such as a wafer, is positioned during etching. The lower electrode **206** is surrounded by a focus ring **210**. A grounded shield **219** surrounds the focus ring **210**. An RF power supply **212** supplies RF power to lower electrode **206**. A plasma is generated in the region **214** above substrate **208**. Confinement rings **216** help confine the etching plasma to the confinement region **214** to improve process control and to ensure repeatability. Confinement rings **216** are preferably of a dielectric material such as quartz.

The confinement rings **216** also include at least one cavity **302**, equidistant from each other, as illustrated in FIG. **3**. FIG. **3** illustrates a preferred embodiment in which the confinement rings include three cavities. The cavities **302** may include a slit. Each slit receives an electrically conductive member **218** that may not contact the confinement rings **216**. The slits are preferably positioned equidistantly between the inner edge and the outer edge of the confinement rings **216** as illustrated in FIG. **3** to deeply bury and isolate the magnetic fields generated by the members **218**. Such members **218** may preferably include a beam of highly conductive material, such as aluminum. As seen in FIG. **2**, each member **218** may be disposed vertically within the cavities **302** of each confinement ring **216**. The top of each member **218** electrically contacts the upper electrode **204**. The bottom of each member **216** electrically contacts the grounded shield **219**. Therefore, each member **216** is sandwiched between the upper electrode **204** and the grounded shield **219** which also provides support to each member **218**.

The power supply **212** provides an RF current to the lower electrode **206**. During the process, the current travels towards the upper electrode **204** through the confinement region **214**. Because the upper electrode **204** electrically contacts members **218**, the current travels through this preferred path, i.e. Members **218**, towards the grounded shield **219**.

The presence of the members **218** embedded within the cavities **302** of the confinement rings **216** provides a preferred return path that substantially reduces the density of the magnetic fields in the upper portion of annular region **220**, i.e., the region outside of the focus and confinement rings **216**. The confinement rings **216** isolate the plasma and the chamber **202** from the preferred return paths. Being embedded in the confinement rings **216**, the stray magnetic fields are kept from penetrating into the volume between the outer edge of the confinement rings **216** and the chamber **202**, i.e. the region **220**. The plasma stays confined and since the return paths are in the confinement ring area, the plasma cannot damage the return path materials. Therefore the stray magnetic fields are substantially reduced outside the confinement rings **216**.

Other embodiments may exist in which an electrically conductive member connects each ring at least a point inside of the outer circumference of the ring. The magnetic fields generated by the electrically conductive member are substantially reduced from an excluded region when the member is disposed within the ring. The member may include any shape or form that allows the current to return to the ground while substantially reducing the magnetic fields generated by the member. Examples of members may be rods, strings, or beams connecting the rings at least at a point inside of the outer circumference of the rings.

While embodiments and applications of this invention have been shown and described, it would be apparent to those skilled in the art having the benefit of this disclosure that many more modifications than mentioned above are possible without departing from the inventive concepts herein. The invention, therefore, is not to be restricted except in the spirit of the appended claims.

What is claimed is:

1. A plasma processing apparatus having a top electrode, a bottom electrode, an interaction space confined between the top electrode and the bottom electrode, said plasma processing apparatus comprising:

- a stack of confinement rings, made of electrically insulating material, spaced apart from each other to form slots therebetween and positioned to surround the interaction space, each confinement ring having at least one cavity formed on the surface thereof;
- a focus ring positioned to surround the bottom electrode;
- an electrically conductive member passing through each of said cavity of said stack of confinement rings, a top of said conductive member electrically coupled to the top electrode, said electrically conductive member is grounded at a bottom thereof.

2. The plasma processing apparatus according to claim **1** wherein each slot is proportioned such that during operation of the plasma processing apparatus, the distance an exiting charged particle must travel in the slot is substantially longer than its mean free path.

3. The plasma processing apparatus according to claim **1** wherein said electrically insulating material comprises quartz.

4. The plasma processing apparatus according to claim **1** wherein said electrically conductive member comprises aluminum.

5. A plasma processing chamber having a top electrode for processing a substrate, the plasma processing chamber comprising:

- a chuck for supporting the substrate during plasma processing;
- a focus ring assembly substantially encircling said chuck;
- a stack of confinement rings, made of electrically insulating material, spaced apart from each other to form slots therebetween, said stack of confinement rings surrounding an interaction space defined between the top electrode and said chuck; each confinement ring having at least one cavity formed on the surface thereof, and
- at least one electrically conductive member passing through each of said cavity of said stack of confinement rings, a top of said at least one conductive member electrically coupled to the top electrode, said electrically conductive member is grounded at a bottom thereof.

6. The plasma processing chamber according to claim **5** wherein said electrically insulating material comprises quartz.

7. The plasma processing chamber according to claim **5** wherein said electrically conductive member comprises aluminum.

8. A plasma processor for processing a workpiece comprising an RF source arrangement, a processing chamber having (a) an exterior wall, (b) a top electrode assembly, (c) a bottom electrode assembly having a holder for the workpiece, (d) an inlet for gas to be converted to a plasma in a region spaced from the wall and between the top and bottom electrode assemblies, (e) a gas outlet, and (f) a confinement structure between the top and bottom electrode assemblies; the top and bottom electrode assemblies being electrically coupled with the RF source arrangement for exciting the gas in the region to a plasma while the plasma is processing the workpiece; the confinement structure being arranged for substantially preventing the plasma in the region from flowing to a portion of the chamber between the confining structure and the exterior wall while enabling un-ionized gas to flow from the region to said portion of the chamber, thence to the outlet; the confinement structure including: (i) at least one confinement ring between the top and bottom electrode assemblies for providing some confinement of the plasma to the region while the plasma is processing the workpiece, and (ii) an electrically conductive member connected to one terminal of the RF source arrangement and being coupled with the RF source arrangement so RF current from the RF source arrangement flows in the electrically conductive member for further confining the plasma to the region while the plasma is processing the workpiece.

9. The plasma processor of claim 8 wherein the confinement ring is a dielectric.

10. The plasma processor of claim 8 wherein the electrically conductive member is received by the confinement ring.

11. A plasma processor for processing a workpiece comprising an RF source, a processing chamber having: (a) an exterior wall, (b) a region spaced from the wall in which a plasma is adapted to be excited, (c) an outlet for gas exhausted from the chamber; the region including (i) a bottom surface comprising an electrode assembly having a holder for the workpiece, (ii) a top surface, and (iii) a side portion including a structure for substantially confining the plasma to the region while the plasma is excited to process the workpiece; the side portion including (a') at least one confinement ring between the top and bottom surfaces, (b') gaps between the confinement ring and the top and bottom surfaces for enabling un-ionized gas to flow from the region to the outlet via a segment of the chamber between the side portion and the

exterior wall, and (c') an electrically conductive member; the confinement ring in combination with the top and bottom surfaces having some confining effect on the plasma in the region while the plasma is excited and is processing the workpiece; the electrically conductive member being coupled to the RF source so RF current from the source flows through the conductive member while the plasma is excited to process the workpiece; the conductive member and coupling of the conductive member to the RF source while the plasma is excited to process the workpiece being such that the RF current flowing in the conductive member while the plasma is excited to process the workpiece produces effects for augmenting the plasma confinement effect of the confinement ring in combination with the top and bottom surfaces.

12. The plasma processor of claim 11 further including a top electrode assembly having a bottom surface including the top surface of the region where the plasma is adapted to be excited.

13. The plasma processor of claim 11 wherein the electrically conductive member is received by the confinement ring.

14. The plasma processor of claim 11 wherein the confinement ring is a dielectric.

15. The plasma processor of claim 11 wherein the electrically conductive member is connected to a terminal of the RF source while the plasma is excited to process the workpiece.

16. A method of processing a workpiece in a plasma processor including an RF source arrangement and a processing chamber having (a) an exterior wall, (b) a top electrode assembly, (c) a bottom electrode assembly having a holder for the workpiece, (d) an inlet for gas to be converted to a plasma in a region spaced from the wall and between the top and bottom electrode assemblies, (e) a gas outlet, and (f) a confinement structure between the top and bottom electrode assemblies; the confinement structure being arranged for substantially preventing the plasma in the region from flowing to a portion of the chamber between the confining structure and the exterior wall while enabling un-ionized gas to flow from the region to said portion of the chamber, thence to the outlet; the confinement structure including: (i) at least one confinement ring between the top and bottom electrode assemblies for providing some confinement of the plasma to the region while the plasma is processing the workpiece, and (ii) an electrically conductive member; the method comprising: supplying gas to the region via the inlet, exciting the gas in the region to a plasma that processes the workpiece by supplying RF energy to electrodes of the top and bottom electrode assemblies, processing the workpiece with charged particles of the plasma excited by the RF energy supplied to the electrodes of the top and bottom electrode assemblies, causing RF current from the RF source arrangement to flow in the electrically conductive member while the charged particles of the plasma are excited by the RF energy and the plasma is processing the workpiece, the RF current flowing in the electrically conductive member while the charged particles of the plasma are excited by the RF energy and the plasma is processing the workpiece producing confinement effects that augment confinement effects of the at least one confinement ring.

17. The method of claim 16 wherein the step of causing RF current from the RF source arrangement to flow in the electrically conductive member includes causing a terminal of the RF source arrangement to be connected to the electrically conductive member while the charged particles of the plasma are excited by the RF energy and the plasma is processing the workpiece.

18. A method of processing a workpiece in a plasma processor including an RF source arrangement and a processing chamber having: (a) an exterior wall, (b) a region spaced from the wall in which a plasma is adapted to be excited, (c) an outlet for gas exhausted from the chamber; the region including (i) a bottom surface comprising an electrode assembly having a holder for the workpiece, (ii) a top surface, and (iii) a side portion including a structure for substantially confining the plasma to the region while the plasma is excited to process the workpiece; the side portion including (a') at least one confinement ring between the top and bottom surfaces, (b') gaps between the confinement ring and the top and bottom surfaces for enabling un-ionized gas to flow from the region to the outlet via a segment of the chamber between the side portion and the exterior wall, and (c') an electrically conductive member; the confinement ring in combination with the top and bottom surfaces having some confining effect on the plasma in the region while the plasma is excited and is processing the workpiece; the method comprising: supplying gas to the region via an inlet to the region, exciting the gas in the region to a plasma that processes the workpiece by supplying RF energy to the region, processing the workpiece with charged particles of the plasma excited by the RF energy supplied to the region, causing RF current from the RF source arrangement to flow in the electrically conductive member while the charged particles of the plasma are excited by the RF energy and the plasma is processing the workpiece, the RF current flowing in the electrically conductive member while the charged particles of the plasma are excited by the RF energy and the plasma is processing the workpiece producing confinement effects that augment confinement effects of the at least one confinement ring.

19. The method of claim 18 wherein the step of causing RF current from the RF source arrangement to flow in the electrically conductive member includes causing a terminal of the RF source arrangement to be connected to the electrically conductive member while the charged particles of the plasma are excited by the RF energy and the plasma is processing the workpiece.

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