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Electrostatic chuck for use in semiconductor processing

Abstract

A semiconductor substrate processing apparatus includes a vacuum chamber having a processing zone in which a semiconductor substrate may be processed, a process gas source in fluid communication with the vacuum chamber for supplying a process gas into the vacuum chamber, a showerhead module through which process gas from the process gas source is supplied to the processing zone of the vacuum chamber, and a substrate pedestal module. The substrate pedestal module includes a pedestal made of ceramic material having an upper surface configured to support a semiconductor substrate thereon during processing, a stem made of ceramic material, and coplanar electrodes embedded in the platen, the electrodes including an outer RF electrode and inner electrostatic clamping electrodes, the outer RF electrode including a ring-shaped electrode and a radially extending lead extending from the ring-shaped electrode to a central portion of the platen, wherein the ceramic material of the platen and the electrodes comprise a unitary body made in a single sintering step.

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Background/Summary

INCORPORATION BY REFERENCE
(1) An Application Data Sheet is filed concurrently with this specification as part of the present application. Each application that the present application claims benefit of or priority to as identified in the concurrently filed Application Data Sheet is incorporated by reference herein in their entireties and for all purposes.
FIELD OF THE INVENTION
(2) This invention pertains to semiconductor substrate processing apparatuses for processing semiconductor substrates, and may find particular use in plasma-enhanced chemical vapor depositions processing apparatuses operable to deposit thin films.
BACKGROUND
(3) Semiconductor substrate processing apparatuses are used to process semiconductor substrates by techniques including etching, physical vapor deposition (PVD), chemical vapor deposition (CVD), plasma-enhanced chemical vapor deposition (PECVD), atomic layer deposition (ALD), plasma-enhanced atomic layer deposition (PEALD), pulsed deposition layer (PDL), plasma-enhanced pulsed deposition layer (PEPDL), and resist removal. One type of semiconductor substrate processing apparatus is a plasma processing apparatus that includes a reaction chamber containing upper and lower electrodes wherein a radio frequency (RF) power is applied between the electrodes to excite a process gas into plasma for processing semiconductor substrates in the reaction chamber.
SUMMARY
(4) Disclosed herein is a semiconductor substrate processing apparatus for processing

semiconductor substrates, comprising a vacuum chamber including a processing zone in which a semiconductor substrate may be processed; a process gas source in fluid communication with the vacuum chamber for supplying a process gas into the vacuum chamber; a showerhead module through which process gas from the process gas source is supplied to the processing zone of the vacuum chamber; and a substrate pedestal module including a platen made of ceramic material having an upper surface configured to support a semiconductor substrate thereon during processing; a stem made of ceramic material having an upper stem flange that supports the platen; and coplanar electrodes embedded in the platen, the electrodes including an outer RF electrode and inner electrostatic clamping electrodes, the outer RF electrode including a ring-shaped electrode and at least one radially extending lead extending from the ring-shaped electrode to a central portion of the platen, wherein the ceramic material of the platen and the electrodes comprise a unitary body made in a single sintering step.

(5) According to an embodiment, the platen includes first and second D-shaped electrostatic clamping electrodes inward of the ring-shaped electrode, the radially extending lead extending diagonally across the platen and connected to the ring-shaped electrode at two locations 180° apart with the first and second D-shaped electrodes on opposite sides of the radially extending lead. The platen can include a first terminal at a center of the platen, a second terminal radially offset from the first terminal, and a third terminal radially offset from the first terminal, the first terminal electrically connected to the radially extending lead of the ring-shaped electrode, the second terminal electrically connected to the first D-shaped electrode and the third terminal electrically connected to the second D-shaped electrode. The first, second and third terminals can extend axially through openings in the platen and the second and third terminals can be aligned along a diagonal line passing through the location of the first terminal.

(6) In another arrangement, the platen can include first, second, third and fourth electrostatic clamping electrodes inward of the ring-shaped electrode, the at least one radially extending feed strip comprising two feed strips extending diagonally across the platen, each of the feed strips connected to the ring-shaped electrode at two locations 180° apart, the feed strips intersecting at the center of the platen with the first, second, third and fourth electrostatic clamping electrodes located between the diagonally extending feed strips.

(7) The platen can be made of any suitable ceramic material and the electrodes can be made of any suitable electrically conductive material. For example, the platen can be made of aluminum nitride and the electrodes can be made of tungsten. The platen can include three through holes configured to receive lift pins and the platen can have a diameter of at least 300 mm.

(8) In the embodiment wherein the electrostatic clamping electrodes are D-shaped electrodes, the ring-shaped electrode can be separated from the D-shaped electrodes by a first continuous wall of ceramic material extending around the first D-shaped electrode and a second continuous wall of ceramic material extending around the second D-shaped electrode. The first and second walls of ceramic material can have the same width with the width of the first and second walls of ceramic material being less than a width of the radially extending lead.

(9) Also disclosed herein is an electrostatic chuck useful for processing semiconductor substrates in a vacuum chamber including a processing zone in which a semiconductor substrate may be processed. The electrostatic chuck comprises a platen made of ceramic material having an upper surface configured to support a semiconductor substrate thereon during processing and coplanar electrodes embedded in the platen. The electrodes include an outer RF electrode and inner electrostatic clamping electrodes, the outer RF electrode including a ring-shaped electrode and at least one radially extending lead extending from the ring-shaped electrode to a central portion of the platen, wherein the ceramic material of the platen and the electrodes comprise a unitary body made in a single sintering step.

Description

BRIEF DESCRIPTION OF THE DRAWING FIGURES

(1) FIG. **1** illustrates a schematic diagram showing an overview of a chemical deposition apparatus in accordance with embodiments disclosed herein.

(2) FIG. **2** shows a top view of a ceramic high temperature chuck wherein a power distribution circuit is located below three coplanar electrodes.

(3) FIG. **3** is an exploded view of the coplanar electrodes shown in FIG. **2** and a power distribution circuit below the electrodes.

(4) FIG. **4** is a bottom view of the chuck shown in FIG. **3**.

(5) FIG. **5** is a top perspective view of a ceramic high temperature electrostatic chuck wherein an outer ring-shaped electrode includes a radially extending lead which can be electrically connected to a centrally located terminal on an underside of the chuck.

(6) FIG. **6** is a bottom perspective view of the chuck shown in FIG. **5**.

(7) FIG. **7** is a cutaway view showing electrical connections of the platen shown in FIG. **5**.

(8) FIG. **8** is a perspective view of an underside of the platen shown in FIG. **5**.

(9) FIG. **9** is a cross section of the platen shown in FIG. **5**.

DETAILED DESCRIPTION

(10) In the following detailed description, numerous specific embodiments are set forth in order to provide a thorough understanding of the apparatus and methods disclosed herein. However, as will be apparent to those skilled in the art, the present embodiments may be practiced without these specific details or by using alternate elements or processes. In other instances, well-known processes, procedures, and/or components have not been described in detail so as not to unnecessarily obscure aspects of embodiments disclosed herein. As used herein the term “about” refers to ±10%.

(11) As indicated, present embodiments provide apparatus and associated methods for processing a semiconductor substrate in a semiconductor substrate processing apparatus such as a chemical vapor deposition apparatus or a plasma-enhanced chemical vapor deposition apparatus. The apparatus and methods are particularly applicable for use in conjunction with high temperature processing of semiconductor substrates such as a high temperature deposition processes wherein a semiconductor substrate being processed is heated to temperatures greater than about 550° C., such as about 550° C. to about 650° C. or more.

(12) Embodiments disclosed herein are preferably implemented in a plasma-enhanced chemical deposition apparatus (i.e. PECVD apparatus, PEALD apparatus, or PEPDL apparatus), however, they are not so limited.

(13) FIG. **1** provides a simple block diagram depicting various semiconductor substrate plasma processing apparatus components arranged for implementing embodiments as disclosed herein. As shown, a semiconductor substrate plasma processing apparatus **100** includes a vacuum chamber **102** that serves to contain plasma in a processing zone, which is generated by a capacitor type system including a showerhead module **104** having an upper RF electrode (not shown) therein working in conjunction with a substrate pedestal module **106** having a lower RF electrode (not shown) therein. At least one RF generator is operable to supply RF energy into a processing zone above an upper surface of a semiconductor substrate **108** in the vacuum chamber **102** to energize process gas supplied into the processing zone of the vacuum chamber **102** into plasma such that a plasma deposition process may be performed in the vacuum chamber **102**. For example, a high-frequency RF generator **110** and a low-frequency RF generator **112** may each be connected to a matching network **114**, which is connected to the upper RF electrode of the showerhead module **104** such that RF energy may be supplied to the processing zone above the semiconductor substrate **108** in the vacuum chamber **102**.

(14) The power and frequency of RF energy supplied by matching network **114** to the interior of the vacuum chamber **102** is sufficient to generate plasma from the process gas. In an embodiment both the high-frequency RF generator **110** and the low-frequency RF generator **112** are used, and in an alternate embodiment, just the high-frequency RF generator **110** is used. In a process, the high-frequency RF generator **110** may be operated at frequencies of about 2-100 MHz; in a preferred embodiment at 13.56 MHz or 27 MHz. The low-frequency RF generator **112** may be operated at about 50 kHz to 2 MHz; in a preferred embodiment at about 350 to 600 kHz. The process parameters may be scaled based on the chamber volume, substrate size, and other factors. Similarly, the flow rates of process gas, may depend on the free volume of the vacuum chamber or processing zone.

(15) An upper surface of the substrate pedestal module **106** supports a semiconductor substrate **108** during processing within the vacuum chamber **102**. The substrate pedestal module **106** can include a chuck to hold the semiconductor substrate and/or lift pins to raise and lower the semiconductor substrate before, during and/or after the deposition and/or plasma treatment processes. In an alternate embodiment, the substrate pedestal module **106** can include a carrier ring to raise and lower the semiconductor substrate before, during and/or after the deposition and/or plasma treatment processes. The chuck may be an electrostatic chuck, a mechanical chuck, or various other types of chuck as are available for use in the industry and/or research. Details of a lift pin assembly for a substrate pedestal module including an electrostatic chuck can be found in commonly-assigned U.S. Pat. No. 8,840,754, which is incorporated herein by reference in its entirety. Details of a carrier ring for a substrate pedestal module can be found in commonly-assigned U.S. Pat. No. 6,860,965, which is incorporated herein by reference in its entirety. A backside gas supply **116** is operable to supply a heat transfer gas or purge gas through the substrate pedestal module **106** to a region below a lower surface of the semiconductor substrate during processing. The substrate pedestal module **106** includes the lower RF electrode therein wherein the lower RF electrode is preferably grounded during processing, however in an alternate embodiment, the lower RF electrode may be supplied with RF energy during processing.

(16) To process a semiconductor substrate in the vacuum chamber **102** of the semiconductor substrate plasma processing apparatus **100**, process gases are introduced from a process gas source **118** into the vacuum chamber **102** via inlet **120** and showerhead module **104** wherein the process gas is formed into plasma with RF energy such that a film may be deposited onto the upper surface of the semiconductor substrate. In an embodiment, multiple source gas lines **122** may be connected to a heated manifold **124**. The gases may be premixed or supplied separately to the chamber. Appropriate valving and mass flow control mechanisms are employed to ensure that the correct gases are delivered through the showerhead module **104** during semiconductor substrate processing. During the processing, a backside heat transfer gas or purge gas is supplied to a region below a lower surface of the semiconductor substrate supported on the substrate pedestal module **102**. Preferably, the processing is at least one of chemical vapor deposition processing, plasma-enhanced chemical vapor deposition processing, atomic layer deposition processing, plasma-enhanced atomic layer deposition processing, pulsed deposition layer processing, or plasma-enhanced pulsed deposition layer processing.

(17) In certain embodiments, a system controller **126** is employed to control process conditions during deposition, post deposition treatments, and/or other process operations. The controller **126** will typically include one or more memory devices and one or more processors. The processor may include a CPU or computer, analog and/or digital input/output connections, stepper motor controller boards, etc.

(18) In certain embodiments, the controller **126** controls all of the activities of the apparatus. The system controller **126** executes system control software including sets of instructions for controlling the timing of the processing operations, frequency and power of operations of the low-frequency RF generator **112** and the high-frequency RF generator **110**, flow rates and temperatures

of precursors and inert gases and their relative mixing, temperature of a semiconductor substrate **108** supported on an upper surface of the substrate pedestal module **106** and a plasma exposed surface of the showerhead module **104**, pressure of the vacuum chamber **102**, and other parameters of a particular process. Other computer programs stored on memory devices associated with the controller may be employed in some embodiments.
(19) High temperature chucks typically include a ceramic pedestal and a smaller diameter ceramic stem joined to the underside of the platen. See, for example, commonly-assigned U.S. Patent Publication Nos. 2016/0340781; 2016/0336213; and 2016/0333475, each of which is hereby incorporated by reference in its entirety.
(20) FIG. **2** shows a platen **200** having three co-planar electrodes **202**, **204**, **206** embedded in a ceramic body (not shown). Electrode **202** is an outer ring-shaped electrode which surrounds D-shaped electrostatic clamping electrodes **204** and **206**. In order to supply power to the outer ring-shaped electrode **202**, a power distribution circuit **208** (see FIG. **3**) is embedded in the ceramic body below the electrodes **202**, **204**, **206** and vertically extending conductive vias **210** connect the outer ring electrode **202** to the power distribution circuit **208**. The power distribution circuit **208** includes an outer ring **212** underlying the outer ring-shaped electrode **202** and arms **214** extending diagonally across the outer ring **212**. The power distribution circuit **208** allows power to be fed from a power feed terminal (not shown) located near the center of the underside of the platen. The electrostatic clamping electrodes **204**, **206** are connected to power feed terminals (not shown) located near the center of the underside of the platen in spaces between the arms **214** of the power distribution circuit **208**.
(21) FIG. **4** shows an underside of the platen **200** wherein the arrangement of electrodes **202**, **204**, **206** can be seen along with terminals **216**, **218**, **220** located inside hollow ceramic stem **222** attached to ceramic body **224**. Terminal **216** is attached to electrostatic clamping electrode **204**, terminal **220** is attached to electrostatic clamping electrode **206**, and terminal **218** is attached to the intersection of arms **214** of power distribution circuit **208**. Thus, to manufacture the platen **200**, it is necessary to carry out multiple sintering steps to embed the conductive power distribution circuit in the ceramic body **224** below the electrodes **202**, **204**, **206** with the result that the arms **214** and ring **212** can act as inductors and create undesired inductance effects during processing of a wafer. The ceramic body **224** includes three through holes **226** sized for passage of lift pins (not shown) for lifting and lowering a wafer onto a support surface of the platen **200**.
(22) FIG. **5** shows an electrostatic chuck comprising platen **300** having an outer ring-shaped electrode **302** surrounding electrostatic clamping electrodes **304**, **306**. The outer ring-shaped electrode **302** is designed in a way which obviates the need for a power distribution circuit. As shown, the outer ring-shaped electrode **302** includes a radially extending lead (power feed strip) **302***a* which extends diagonally across the ring-shaped electrode **302**. The lead **302***a* allows a terminal (not shown) at a center of the underside of the platen **300** to be electrically connected to the outer ring-shaped electrode **302**. The electrostatic chuck is preferably a bipolar chuck with one or more pairs of clamping electrodes having opposed polarities. For instance, the electrostatic chuck can include four clamping electrodes separated by feed strips extending diagonally across the outer ring-shaped electrode **302**. In such case, the feed strips would be perpendicular and the clamping electrodes would be located inside the four quadrant shaped spaces formed by the outer ring-shaped electrode **302** and the diagonally extending feed strips.
(23) FIG. **6** shows an underside of the platen **300** wherein a hollow ceramic stem **322** is attached to ceramic body **324**. Terminal **316** is attached to electrostatic clamping electrode **304**, terminal **320** is attached to electrostatic clamping electrode **306**, and terminal **318** is attached to lead **302***a* of the ring-shaped outer electrode **302**. The ceramic body **324** includes three through holes **326** sized for passage of lift pins (not shown) for lifting and lowering a wafer onto a support surface of the platen **300**.
(24) The platen **300** can be used as a high temperature electrostatic chuck of a substrate support

module for sequential processing of individual semiconductor wafers wherein the platen **300** is a unitary body made in a single sintering step to provide coplanar electrostatic clamping and RF electrodes and one or more heaters below the coplanar electrodes. As mentioned above, in prior platen designs, an embedded power distribution circuit below the RF and electrostatic clamping electrodes included power distribution electrode arms which created undesirable inductance effects during wafer processing. By eliminating the power distribution electrode arms, it is possible to eliminate out-of-plane inductors and simplify the manufacturing process by conducting a single sintering step. In addition, by providing a feed strip **302** which extends diagonally across the outer ring-shaped electrode **302**, it is possible to minimize adverse effects of disturbances to the RF field above the wafer being processed.

(25) The pedestal **300** and stem **322** are preferably of ceramic material and a bottom surface of the pedestal **300** can be joined to a flange at an upper end of the stem **322** such as by brazing, friction welding, diffusion bonding, or other suitable technique. The interior of the stem **322** can include power supply leads, one or more thermocouple leads, and one or more gas supply tubes which supply an inert gas such as argon (Ar) or a heat transfer gas such as helium (He) which is delivered via suitable fluid passages to an underside of a semiconductor substrate located on support surface.

(26) The power leads can be one or more feed rods which supply radio-frequency (RF), direct current (DC) and/or alternating current (AC) to electrodes embedded in the pedestal **300**. The pedestal **300** is preferably a unitary body of sintered ceramic material such as aluminum oxide (alumina), yttria, aluminum nitride, boron nitride, silicon oxide, silicon carbide, silicon nitride, titanium oxide, zirconium oxide, or other suitable material or combination of materials. Each electrode preferably has a planar configuration and is preferably made of an electrically conductive metallic material (e.g., tungsten, molybdenum, tantalum, niobium, cobalt) or electrically conductive non-metallic material (e.g., aluminum oxide-tantalum carbide, aluminum oxide-silicon carbide, aluminum nitride-tungsten, aluminum nitride-tantalum, yttrium oxide-molybdenum). The electrodes can be formed from powder materials which are co-fired with the ceramic material of the pedestal. For example, the electrodes can be formed of conductive paste which is co-fired with layers of the ceramic material forming the body of the pedestal. For example, the paste can include conductive metal powder of nickel (Ni), tungsten (W), molybdenum (Mo), titanium (Ti), manganese (Mn), copper (Cu), silver (Ag), palladium (Pd), platinum (Pt), rhodium (Rh), Alternatively, the electrodes can be formed from a deposited material having a desired electrode pattern or a deposited film which is etched to form a desired electrode pattern. Still yet, the electrodes can comprise preformed grids, plates, wire mesh, or other suitable electrode material and/or configuration. In an embodiment, the electrodes include at least one electrostatic clamping electrode which is powered by a DC power source to provide DC chucking voltage (e.g., about 200 to about 2000 volts), at least one RF electrode powered by a RF power source to provide RF bias voltage (e.g., one or more frequencies of about 400 KHz to about 60 MHz at power levels of about 50 to about 3000 watts) and/or at least one electrode powered by DC and RF power sources via suitable circuitry.

(27) The platen can be made by arranging coplanar electrodes in ceramic material and conducting a single sintering step to embed the electrodes in the sintered ceramic material. Examples of techniques for manufacturing ceramic chucks can be found in commonly-assigned U.S. Pat. Nos. 5,880,922; 6,483,690; and 8,637,194, the disclosures of which are hereby incorporated by reference. For example, the outer ring-shaped electrode with integral radially extending lead and the ESC electrodes can be screen printed on a green sheet of aluminum nitride, a green sheet of aluminum nitride or other suitable dielectric material can be placed over the screen printed electrodes, and the resulting compact can be heated pressed and sintered to form the platen. Terminals in holes extending into the underside of the sintered ceramic material can be bonded to each of the electrodes and the stem can be bonded to the underside of the platen.

(28) FIG. **7** illustrates a platen **300** which includes electrically conductive electrodes **304**, **306** such

as an electrically conductive grids and feed strip electrode **302***a* which is electrically connected to an outer ring-shaped electrode **302** (not shown) embedded therein and a hollow ceramic support stem **322**. The platen **300** and stem **322** are preferably made of a ceramic material such as aluminum nitride and a bottom surface of the platen **300** is joined to an upper end of the stem **322** such as by brazing, friction welding, diffusion bonding, or other suitable technique. A centrally located electrically conductive tube **330** is located inside the stem **322** with an upper end of the tube **330** electrically connected to embedded feed strip electrode **302***a*. An outlet of the tube **330** is in fluid communication with a gas passage **342** in an upper surface of the platen **300**. The tube **330** can be supplied an inert gas such as argon (Ar) or nitrogen (N.sub.2) or a heat transfer gas such as helium (He) which is delivered via gas passage **342** to an underside of a semiconductor substrate (not shown) supported on the platen **300**. The outer surface of the tube **330** can be sealed to the platen **300** by a hermetic seal **332**. The inside of the stem **322** also houses other components such as electrical feed rods **338** which deliver power to other electrodes such as resistance heaters **340***a*, **340***b* and additional feed rods **336** which deliver power to electrostatic clamping electrodes **304**, **306** in the platen **300**. The rods **336** can be hollow for deliver gas through outlets to the underside of a wafer supported on the pedestal **300**.

(29) During processing of a semiconductor substrate such as deposition of films on a silicon wafer supported on the platen **300**, the platen **300** may cycle between temperatures ranging from about 20° C. to 500° c. and higher. For processing a 300 mm wafer, the platen **300** can have a thickness of up to about 1 inch and a diameter of about 15 inches, the stem **322** can have a diameter of about 3 inches and the distance between the bottom of the stem **322** and the upper surface of the platen **300** can be about 5 inches. The tubes **330**, **336** can have a diameter of about 4 mm, a length of about 7 to 8 inches. The inside of the stem **322** accommodates components such as electrical feeds such as palladium/rhodium (Pd/Rh) coated stainless steel or nickel (Ni) rods.

(30) The feed rods **338** can be solid metal rods such as nickel (Ni) rods arranged at circumferentially spaced apart locations inward of an inner surface of the stem **322**, and the two outer electrically conductive feed rods **336** (which can optionally be hollow rods to deliver gas to the upper surface of platen **300**) are electrically connected to electrostatic clamping electrodes **304**, **306**. The solid feed rods **338** can supply power to resistance heaters **340***a*, **340***b* embedded in the platen **300** at a location below the electrostatic clamping electrodes **304**, **306**. Electrical connections between the central tube **330** and feed strip **302***a*, between the feed rods **336** and the electrodes **304**, **306**, and between the feed rods **338** and the heaters **340***a*, **340***b* can include solid terminals/studs/sockets as disclosed in commonly-assigned U.S. Pat. No. 9,088,085, the disclosure of which is hereby incorporated by reference. During manufacture of the platen **300**, the tube **330** and feed rods **336**, **338** can be bonded to the platen **300** and electrodes **302**, **304**, **306** via suitable sintering and/or brazing techniques.

(31) FIG. **8** shows a bottom perspective view of the substrate support pedestal **106**. As shown, central tube **330**, feed rods **338** and outer tubes **336** extend outward from a lower end of the stem **322**.

(32) FIG. **9** is a cross-sectional view of the substrate support pedestal **106**. As shown, the central tube **330** is electrically connected to feed strip electrode **302***a* and two feed rods **338** are electrically connected to one or more resistance heaters **340***a*, **340***b* embedded in the platen **300** at a location below the electrodes **302**, **304**, **306**. For instance, a pair of feed rods **338** can be connected to an inner heater and another pair of feed rods **338** can be connected to an outer heater. If desired a single heater or more than two heaters can be embedded in the platen **300** in any desired geometrical arrangement. The central tube **330** supplies gas to an outlet **342** in the upper surface of the platen **300**.

(33) While the substrate pedestal module of the semiconductor substrate processing apparatus has been described in detail with reference to specific embodiments thereof, it will be apparent to those

skilled in the art that various changes and modifications can be made, and equivalents employed, without departing from the scope of the appended claims.

Claims

1. An electrostatic chuck, comprising: a platen having an upper surface configured to support a substrate; a first electrostatic clamping electrode embedded within the platen; a second electrostatic clamping electrode embedded within the platen; an outer ring-shaped RF electrode, embedded within the platen, that surrounds the first and second electrostatic clamping electrodes and comprises a feed strip that extends radially across the platen between the first and second electrostatic clamping electrodes; and a plurality of hollow feed rods configured to supply power to the first and second electrostatic clamping electrodes and to the outer ring-shaped RF electrode.
2. The electrostatic chuck of claim 1, wherein the first and second electrostatic clamping electrodes have opposite polarities.
3. The electrostatic chuck of claim 1, wherein the first and second electrostatic clamping electrodes are configured to be powered by a DC chucking voltage between about 200 V and about 2000 V to electrostatically clamp the substrate, and wherein the outer ring-shaped RF electrode is configured to be powered by an RF power source configured to provide an RF bias voltage at a frequency between about 400 kHz and about 60 MHz at a power between about 50 W and about 3000 W.
4. The electrostatic chuck of claim 1, further comprising: a stem attached to the platen; and at least three terminals located inside the stem.
5. The electrostatic chuck of claim 4, wherein the plurality of hollow feed rods are located inside the stem and configured to supply the power to the first and second electrostatic clamping electrodes and the outer ring-shaped RF electrode via the at least three terminals.
6. The electrostatic chuck of claim 1, wherein the outer ring-shaped RF electrode, the first electrostatic clamping electrode, and the second electrostatic clamping electrode are coplanar.
7. The electrostatic chuck of claim 1, further comprising: a plurality of resistance heaters embedded in the platen at a location beneath the first and second electrostatic clamping electrodes.
8. The electrostatic chuck of claim 1, wherein the feed strip extends diagonally across the platen between the first and second electrostatic clamping electrodes to connect to the outer ring-shaped RF electrode at two locations 180 degrees apart.