FIG. 17 is a flowchart of a plasma processing method according to still another exemplary embodiment.

FIG. 18 is a diagram of an example measurer used with the plasma processing apparatuses according to the various exemplary embodiments.

FIG. 19 is a diagram of an edge ring and a conductive ring in still another exemplary embodiment.

FIG. 20 is a diagram of an edge ring and a conductive ring in still another exemplary embodiment.

FIG. 21 is a diagram of a substrate support and a lifter in still another exemplary embodiment.

FIG. 22 is a graph showing experimental results.

FIG. 23 is a diagram of a substrate support and a lifter in one exemplary embodiment.

DETAILED DESCRIPTION

[0008] Exemplary embodiments will now be described in detail with reference to the drawings. In the drawings, like reference numerals denote like or corresponding components.

[0009] FIG. 1 is a diagram of a plasma processing system with an example structure. In one or more embodiments, the plasma processing system includes a plasma processing apparatus 1 and a controller 2. The plasma processing system is an example of a substrate processing system. The plasma processing apparatus 1 is an example of a substrate processing apparatus. The plasma processing apparatus 1 includes a plasma processing chamber 10, a substrate support 11, and a plasma generator 12. The plasma processing chamber 10 has a plasma processing space. The plasma processing chamber 10 has at least one gas inlet for supplying at least one process gas into the plasma processing space and at least one gas outlet for discharging the gas from the plasma processing space. The gas inlet is connected to a gas supply 20 (described later). The gas outlet is connected to an exhaust system 40 (described later). The substrate support 11 is located in the plasma processing space and has a substrate support surface for supporting a substrate.

[0010] The plasma generator 12 generates plasma from at least one process gas supplied into the plasma processing space. The plasma generated in the plasma processing space may be capacitively coupled plasma (CCP), inductively coupled plasma (ICP), electron cyclotron resonance (ECR) plasma, helicon wave plasma (HWP), or surface wave plasma (SWP). Various plasma generators including an alternating current (AC) plasma generator and a direct current (DC) plasma

generator may be used. In one or more embodiments, an AC signal (AC power) used in the AC plasma generator has a frequency in a range of 100 kHz to 10 GHz. Thus, the AC signal includes a radio-frequency (RF) signal and a microwave signal. In one or more embodiments, the RF signal has a frequency in a range of 100 kHz to 150 MHz.

[0011] The controller 2 processes computer-executable instructions that cause the plasma processing apparatus 1 to perform various steps described in one or more embodiments of the disclosure. The controller 2 may control the components of the plasma processing apparatus 1 to perform the various steps described herein. In one or more embodiments, some or all of the components of the controller 2 may be included in the plasma processing apparatus 1. The controller 2 may include a processor 2a1, a storage 2a2, and a communication interface 2a3. The controller 2 is implemented by, for example, a computer 2a. The processor 2a1 may perform various control operations by loading a program from the storage 2a2 and executing the loaded program. The program may be prestored in the storage 2a2 or may be obtained through a medium as appropriate. The obtained program is stored into the storage 2a2 to be loaded from the storage 2a2 and executed by the processor 2a1. The medium may be one of various storage media readable by the computer 2a, or a communication line connected to the communication interface 2a3. The processor 2a1 may be a central processing unit (CPU). The storage 2a2 may include a random-access memory (RAM), a read-only memory (ROM), a hard disk drive (HDD), a solid-state drive (SSD), or a combination of these. The communication interface 2a3 may communicate with the plasma processing apparatus 1 through a communication line such as a local area network (LAN).

[0012] An example structure of an inductively coupled plasma processing apparatus as an example of the plasma processing apparatus 1 will now be described. FIG. 2 is a diagram of the inductively coupled plasma processing apparatus with an example structure.

[0013] The inductively coupled plasma processing apparatus 1 includes a plasma processing chamber 10, a gas supply 20, a power supply 30, and an exhaust system 40. The plasma processing chamber 10 includes a dielectric window 101. The plasma processing apparatus 1 also includes a substrate support 11, a gas guide unit, and an antenna 14. The substrate support 11 is located in the plasma processing chamber 10. The antenna 14 is located on or above the plasma processing chamber 10 (more specifically, on or above the dielectric window 101). The plasma

processing chamber 10 has a plasma processing space 10s defined by the dielectric window 101, a sidewall 102 of the plasma processing chamber 10, and the substrate support 11. The plasma processing chamber 10 is grounded.

[0014] The substrate support 11 includes a body 111 and a ring assembly 112. The body 111 includes a central area 111a for supporting a substrate W and an annular area 111b for supporting the ring assembly 112. A wafer is an example of the substrate W. The annular area 111b of the body 111 surrounds the central area 111a of the body 111 as viewed in plan. The substrate W is placed on the central area 111a of the body 111. The ring assembly 112 is placed on the annular area 111b of the body 111 to surround the substrate W on the central area 111a of the body 111. Thus, the central area 111a is also referred to as a substrate support surface for supporting the substrate W. The annular area 111b is also referred to as a ring support surface for supporting the ring assembly 112.

[0015] In one or more embodiments, the body 111 includes a base 1110 and an electrostatic chuck (ESC) 1111. The base 1110 includes a conductive member. The conductive member in the base 1110 may serve as a bias electrode. The ESC 1111 is located on the base 1110. The ESC 1111 includes a ceramic member 1111a and an electrostatic electrode 1111b inside the ceramic member 1111a. The ceramic member 1111a includes the central area 111a. In one or more embodiments, the ceramic member 1111a also includes the annular area 111b. Another member surrounding the ESC 1111, such as an annular ESC or an annular insulating member, may include the annular area 111b. In this case, the ring assembly 112 may be located on either the annular ESC or the annular insulating member, or may be located on both the ESC 1111 and the annular insulating member. At least one RF/DC electrode coupled to an RF power supply 31, a DC power supply 32, or both (described later) may be located inside the ceramic member 1111a. In this case, at least one RF/DC electrode serves as a bias electrode. The conductive member in the base 1110 and at least one RF/DC electrode may serve as multiple bias electrodes. The electrostatic electrode 1111b may also serve as a bias electrode. Thus, the substrate support 11 includes at least one bias electrode.

[0016] The ring assembly 112 includes one or more annular members. In one or more embodiments, one or more annular members include one or more edge rings and at least one cover ring. The edge ring

is formed from a conductive material or an insulating material. The cover ring is formed from an insulating material.

[0017] The substrate support 11 may also include a temperature control module that adjusts the temperature of at least one of the ESC 1111, the ring assembly 112, or the substrate to be a target temperature. The temperature control module may include a heater, a heat transfer medium, a channel 1110a, or a combination of these. The channel 1110a allows a heat transfer fluid such as brine or gas to flow. In one or more embodiments, the channel 1110a is defined in the base 1110, and one or more heaters are located in the ceramic member 1111a in the ESC 1111. The substrate support 11 may include a heat transfer gas supply to supply a heat transfer gas into a space between the back surface of the substrate W and the central area 111a.

[0018] The gas guide unit introduces at least one process gas from the gas supply 20 into the plasma processing space 10s. In one or more embodiments, the gas guide unit includes a central gas injector (CGI) 13. The CGI 13 is located above the substrate support 11 and installed in a central opening in the dielectric window 101. The CGI 13 has at least one gas inlet 13a, at least one gas channel 13b, and at least one gas guide 13c. The process gas supplied to the gas inlet 13a passes through the gas channel 13b and is introduced into the plasma processing space 10s through the gas guide 13c. In addition to or in place of the CGI 13, the gas guide unit may include one or more side gas injectors (SGIs) installed in one or more openings in the sidewall 102.

[0019] The gas supply 20 may include at least one gas source 21 and at least one flow controller 22. In one or more embodiments, the gas supply 20 supplies at least one process gas from the corresponding gas source 21 to the gas guide unit through the corresponding flow controller 22. The flow controller 22 may include, for example, a mass flow controller or a pressure-based flow controller. The gas supply 20 may further include at least one flow rate modulator that allows supply of at least one process gas at a modulated flow rate or in a pulsed manner.

[0020] The power supply 30 includes an RF power supply 31 that is coupled to the plasma processing chamber 10 through at least one impedance matching circuit. The RF power supply 31 provides at least one RF signal (RF power) to at least one bias electrode and the antenna 14. This causes plasma to be generated from at least one process gas supplied into the plasma processing space 10s. The RF power supply 31 may thus at least partially serve as the plasma generator 12.

A bias RF signal is provided to at least one bias electrode to generate a bias potential in the substrate W, thus drawing ions in the plasma to the substrate W.

[0021] In one or more embodiments, the RF power supply 31 includes a first RF generator 31a and a second RF generator 31b. The first RF generator 31a is coupled to the antenna 14 through at least one impedance matching circuit to generate a source RF signal (source RF power) for generating plasma. In one or more embodiments, the source RF signal has a frequency in a range of 10 to 150 MHz. In one or more embodiments, the first RF generator 31a may generate multiple source RF signals with different frequencies. The generated one or more source RF signals are provided to the antenna 14.

[0022] The second RF generator 31b is coupled to at least one bias electrode through at least one impedance matching circuit and generates a bias RF signal (bias RF power). The bias RF signal may have a frequency that is the same as or different from the frequency of the source RF signal. In one or more embodiments, the bias RF signal has a lower frequency than the source RF signal. In one or more embodiments, the bias RF signal has a frequency in a range of 100 kHz to 60 MHz. In one or more embodiments, the second RF generator 31b may generate multiple bias RF signals with different frequencies. The generated one or more bias RF signals are provided to at least one bias electrode. In various embodiments, at least one of the source RF signal or the bias RF signal may be pulsed.

[0023] The power supply 30 may include the DC power supply 32 coupled to the plasma processing chamber 10. The DC power supply 32 includes a bias DC generator 32a. In one or more embodiments, the bias DC generator 32a is coupled to at least one bias electrode and generates a bias DC signal. The generated bias DC signal is applied to at least one bias electrode.

[0024] In various embodiments, the bias DC signal may be pulsed. In this case, a sequence of voltage pulses is applied to at least one bias electrode. The voltage pulses may have a rectangular, trapezoidal, or triangular pulse waveform, or a combination of these pulse waveforms. In one or more embodiments, a waveform generator for generating a sequence of voltage pulses based on DC signals is coupled between the bias DC generator 32a and at least one bias electrode. Thus, the bias DC generator 32a and the waveform generator form a voltage pulse generator. The voltage pulses may have positive polarity or negative polarity. The sequence of voltage pulses may include one or more positive voltage pulses and one or more negative voltage pulses within one

cycle. The power supply 30 may include the bias DC generator 32a in addition to the RF power supply 31, or the bias DC generator 32a may replace the second RF generator 31b.

[0025] The antenna 14 includes one or more coils. In one or more embodiments, the antenna 14 may include an outer coil and an inner coil that are coaxial with each other. In this case, the RF power supply 31 may be coupled to both the outer coil and the inner coil, or coupled to either the outer coil or the inner coil. When the RF power supply 31 is coupled to both the outer coil and the inner coil, a single RF generator may be connected to both the outer coil and the inner coil, or separate RF generators may be connected respectively to the outer coil and the inner coil.

[0026] The exhaust system 40 is connectable to, for example, a gas outlet 10e in the bottom of the plasma processing chamber 10. The exhaust system 40 may include a pressure control valve and a vacuum pump. The pressure control valve regulates the pressure in the plasma processing space 10s. The vacuum pump may include a turbomolecular pump, a dry pump, or a combination of these.

[0027] FIG. 3 will now be referred to. FIG. 3 is a diagram of a substrate support and a lifter in one exemplary embodiment. The substrate support 11 and a lifter 50 shown in FIG. 3 may be included in the plasma processing apparatus 1.

[0028] As described above, the substrate support 11 supports an edge ring UR (upper edge ring). The edge ring UR is a part of the ring assembly 112. The edge ring UR surrounds the substrate W on the substrate support 11. The edge ring UR is formed from a conductive material such as silicon, silicon carbide, or tungsten.

[0029] As described above, the substrate support 11 includes the base 1110 and the ESC 1111. The base 1110 is a conductive member or includes a conductive member inside. The base 1110 (or its conductive member) is electrically coupled to at least one bias power supply such as the second RF generator 31b, the bias DC generator 32a, or both. At least one bias power supply generates an electrical bias to draw ions from plasma into the substrate W on the substrate support 11. The electrical bias includes a sequence of the above bias RF signals, the above voltage pulses, or both.

[0030] The ESC 1111 is located on the base 1110. The ESC 1111 includes a first portion P1 and a second portion P2. The first portion P1 includes the substrate support surface (or the central area

111a) as its upper surface. Each of the first portion P1 and the substrate support surface is a substantially circular flat surface. The first portion P1 and the substrate support surface are coaxial with the substrate support 11. The first portion P1 includes the electrostatic electrode 1111b described above. When the electrostatic electrode 1111b receives a DC voltage applied from a DC power supply, an electrostatic attraction is generated between the first portion P1 and the substrate W. The first portion P1 holds the substrate W under the generated electrostatic attraction.

[0031] The second portion P2 extends circumferentially about the central axis of the substrate support 11 to surround the first portion P1. The second portion P2 includes the ring support surface (or the annular area 111b) as its upper surface. Each of the second portion P2 and the ring support surface is a substantially annular flat surface. The second portion P2 may include at least one electrostatic electrode. The second portion P2 may include an electrode BEa and an electrode BEb as at least one electrostatic electrode. The electrode BEa and the electrode BEb form a bipolar electrode. The electrode BEa and the electrode BEb receive a voltage applied from at least one power supply to have a potential difference between them. This generates an electrostatic attraction between the edge ring UR and the second portion P2. The second portion P2 holds the edge ring UR under the generated electrostatic attraction.

[0032] In one or more embodiments, the ring support surface extends at a lower level than the substrate support surface. In this case, the first portion P1 includes a sidewall surface 111s extending between the substrate support surface and the ring support surface. In this case, an edge ring LR (lower edge ring) may be located on the ring support surface along the sidewall surface 111s. The edge ring LR is a part of the ring assembly 112. The edge ring LR may be formed from a conductive material such as silicon, silicon carbide, or tungsten. In some embodiments, the edge ring LR may be formed from an insulating material such as quartz. In this case, the edge ring UR is located on the edge ring LR. The ring support surface and the sidewall surface 111s are protected by the edge ring LR.

[0033] As shown in FIG. 3, the substrate support 11 may further include a cover ring CR and an insulating member IM. The insulating member IM is formed from an insulating material such as quartz, and is substantially cylindrical. The insulating member IM extends circumferentially about the central axis of the substrate support 11 to surround the base 1110 and the ESC 1111. The

cover ring CR is a substantially disk and is located on the insulating member IM to surround the edge ring UR.

[0034] The plasma processing apparatus 1 further includes the lifter 50. The lifter 50 includes a conductive ring 51, at least one rod 52, an actuator 53, and at least one connector 54.

[0035] The conductive ring 51 is formed from a metal such as aluminum or a conductive material, and is substantially a ring. The conductive ring 51 extends circumferentially about the central axis of the substrate support 11 to surround the base 1110 and the ESC 1111 inward from the insulating member IM. The conductive ring 51 is electrically coupled to the edge ring UR while supporting the edge ring UR placed on the conductive ring 51. More specifically, the conductive ring 51 is electrically conductive with or capacitively coupled to the edge ring UR while supporting the edge ring UR placed on the conductive ring 51. In the example in FIG. 3, the conductive ring 51 is conductive with the edge ring UR while supporting the edge ring UR placed on the conductive ring 51. The surface of the conductive ring 51 may have an exposed area covered with a film resistant to the plasma. The film may be formed from a material such as aluminum oxide or yttrium fluoride, and may be formed by anodic oxidation or thermal spraying.

[0036] The rod 52 extends in the vertical direction below the conductive ring 51. The rod 52 may be insulating. This structure can reduce the likelihood that the electrical bias flows into the actuator 53 through the rod 52. In one or more embodiments, the lifter 50 may include multiple rods 52 as at least one rod 52. The multiple rods 52 are arranged circumferentially about the central axis of the substrate support 11. The multiple rods 52 may be arranged circumferentially at equal intervals.

[0037] The actuator 53 is located below the rod 52 and is connected to the rod 52. The actuator 53 raises and lowers the edge ring with the rod 52 and the conductive ring 51. The actuator 53 may be, for example, a pneumatic cylinder, a hydraulic cylinder, or a motor.

[0038] The connector 54 electrically couples the conductive ring 51 and the base 1110 (or its conductive member). The connector 54 maintains the electrical coupling for the movement of the conductive ring 51. The connector 54 may be deformable in response to the movement of the conductive ring 51. The lifter 50 including multiple rods 52 may include multiple connectors 54 as at least one connector 54.

edge ring from the transfer module TM to the process module PM5. The position detection sensors S61 and S62 are installed on the transfer path for the substrate W and the edge ring from the transfer module TM to the process module PM6. The position detection sensors S71 and S72 are installed on the transfer path for the substrate W and the edge ring from the transfer module TM to the process module PM7.

[0051] In one or more embodiments, the transfer robot TR transfers an edge ring for a substrate support in one of the process modules PM1 to PM7. The edge ring corresponds to the edge ring UR or a set of rings including the edge ring UR and the edge ring LR. The edge ring is placed on either of the two picks TP and is transferred. Each pick TP includes a sensor TS. The sensor TS is an optical sensor that measures the position of a ring member, such as the edge ring, on the substrate support.

[0052] Each of the process modules PM1 to PM7 performs dedicated substrate processing and includes a processing chamber (substrate processing chamber). A gate valve is located between each processing chamber and the transfer chamber TC. At least one of the process modules PM1 to PM7 is the plasma processing apparatus 1.

[0053] The stocker module RSM (ring stocker) is connected to the transfer chamber TC with a gate valve. The stocker module RSM includes a chamber that can store multiple edge rings.

[0054] The controller MC controls the components of the substrate processing system PS. The controller MC may be a computer including a processor, a storage, an input device, and a display. The controller MC executes a control program stored in the storage to control the components of the substrate processing system PS based on recipe data stored in the storage.

[0055] The plasma processing apparatus 1 used as the process module in the substrate processing system PS may include the substrate support 11 shown in any one of FIGS. 6 to 9. FIGS. 6 to 9 are each a diagram of a substrate support and a lifter in still another exemplary embodiment. In the embodiments in FIGS. 6 to 9, the edge ring in the plasma processing apparatus 1 is transferred by the transfer robot TR to be replaced with an edge ring in the stocker module RSM corresponding to the transferred edge ring.

[0056] In the embodiment in FIG. 6, the substrate support 11 has multiple through-holes extending through the substrate support 11 in the vertical direction. The through-holes in the substrate support 11 are arranged circumferentially about the central axis of the substrate support 11. The

head 13A. The shower head 13A is located above the substrate support 11. In one or more embodiments, the shower head 13A defines at least a part of the ceiling of the plasma processing chamber 10. The plasma processing chamber 10 has a plasma processing space 10s defined by the shower head 13A, a sidewall 10a of the plasma processing chamber 10, and the substrate support 11. The plasma processing chamber 10 is grounded. The shower head 13A and the substrate support 11 are electrically insulated from the housing of the plasma processing chamber 10.

[0072] The shower head 13A introduces at least one process gas from the gas supply 20 into the plasma processing space 10s. The shower head 13A has at least one gas inlet 13Aa, at least one gas-diffusion compartment 13Ab, and multiple gas guides 13Ac. The process gas supplied to the gas inlet 13Aa passes through the gas-diffusion compartment 13Ab and is introduced into the plasma processing space 10s through the multiple gas guides 13Ac. The shower head 13A also includes at least one upper electrode. In addition to the shower head 13A, the gas guide unit may include one or more side gas injectors (SGIs) installed in one or more openings in the sidewall 10a.

[0073] In the plasma processing apparatus 1 shown in FIG. 10, the base 1110 (or its conductive member), or more specifically, a lower electrode is electrically coupled to an RF power supply, at least one bias power supply, or both. The RF power supply is the first RF generator 31a and is included in the plasma generator 12. At least one bias power supply includes the second RF generator 31b, the bias DC generator 32a (specifically, a first DC generator), or both. At least one bias power supply generates an electrical bias to draw ions from plasma into the substrate W on the substrate support 11. The electrical bias includes a sequence of the above bias RF signals, the above voltage pulses, or both.

[0074] In the plasma processing apparatus 1 shown in FIG. 10, the DC power supply 32 may further include a second DC generator 32b in addition to the bias DC generator 32a, or a first DC generator 32a. In one or more embodiments, the first DC generator 32a is coupled to at least one lower electrode and generates a first DC signal. The generated first DC signal is applied to at least one lower electrode. In one or more embodiments, the second DC generator 32b is coupled to at least one upper electrode and generates a second DC signal. The generated second DC signal is applied to at least one upper electrode.

[0075] In various embodiments, the second DC signal, in addition to the first DC signal, may be

pulsed. In this case, a sequence of voltage pulses is applied to at least one lower electrode, at least one upper electrode, or both. The voltage pulses may have a rectangular, trapezoidal, triangular pulse waveform, or a combination of these pulse waveforms. In one or more embodiments, a waveform generator for generating a sequence of voltage pulses based on DC signals is coupled between the first DC generator 32a and at least one lower electrode. Thus, the first DC generator 32a and the waveform generator form a voltage pulse generator. When the second DC generator 32b and the waveform generator form a voltage pulse generator, the voltage pulse generator is coupled to at least one upper electrode. The voltage pulses may have positive polarity or negative polarity. The sequence of voltage pulses may include one or more positive voltage pulses and one or more negative voltage pulses within one cycle. The power supply 30 may include the first DC generator 32a and the second DC generator 32b in addition to the RF power supply 31. The first DC generator 32a may replace the second RF generator 31b.

[0076] FIG. 11 will now be referred to. FIG. 11 is a diagram of a substrate support and a lifter in still another exemplary embodiment. The substrate support 11 and the lifter 50 shown in FIG. 11 may be included in the inductively coupled plasma processing apparatus 1 or the capacitively coupled plasma processing apparatus 1 described above. The substrate support 11 and the lifter 50 shown in FIG. 11 will now be described focusing on their differences from the substrate support 11 and the lifter 50 shown in FIG. 3.

[0077] The lifter 50 shown in FIG. 11 can electrically couple (e.g., allows electrical conduction between) the conductive ring 51 and the edge ring UR while supporting the edge ring UR on the conductive ring 51, similarly to the lifter 50 shown in FIG. 3. More specifically, the lifter 50 shown in FIG. 11 can establish a first state (e.g., a conductive state between the edge ring UR and the base 1110) in which the edge ring UR and the base 1110 are electrically coupled to each other. The lifter 50 shown in FIG. 11 can lower the conductive ring 51 downward with the rod 52 using the actuator 53 to separate the conductive ring 51 from the edge ring UR. In other words, the lifter 50 shown in FIG. 11 can disconnect the conductive ring 51 from the edge ring UR to establish a second state (e.g., a nonconductive state between the edge ring UR and the base 1110) in which the edge ring UR and the base 1110 are electrically disconnected from each other. The lifter 50 shown in FIG. 11 thus serves as a switch switchable between establishing the first state and establishing

[0087] Step STd is then performed. In step STd, the controller 2 controls the components of the plasma processing apparatus 1 to perform plasma processing based on the recipe described above. When the edge ring UR and the base 1110 are electrically coupled to each other (e.g., electrically conductive) during step STd, the density of the plasma above the edge ring UR is increased in response to a source RF signal, an electrical bias, or both provided from the base 1110 to the edge ring UR through the conductive ring 51.

[0088] For the determination in step STJ, the controller 2 may obtain, from the imaging device 80, an image of the upper surface of a substrate W processed based on the same recipe before the substrate W is placed on the substrate support 11 in the plasma processing apparatus 1. The controller 2 may determine, based on the image, whether the density of the plasma above the edge ring UR is to be increased. In one or more embodiments, multiple holes may be formed in the substrate W in the plasma processing based on the recipe in step STd. In this case, when the controller 2 determines, based on the image obtained from the imaging device 80, that the roundness of the holes in an edge area of the substrate W and in the upper surface of the substrate W is less than or equal to a threshold in step STJ, the controller 2 performs step STb. When determining, based on the image obtained from the imaging device 80, that the roundness is greater than the threshold in step STJ, the controller 2 performs step STc. The roundness may be the ratio of the minimum width to the maximum width of the holes in the edge area of the substrate W and in the upper surface of the substrate W.

[0089] FIG. 15B will now be referred to with FIG. 14. FIG. 15B is a diagram of an example measurer used with the plasma processing apparatuses according to the various exemplary embodiments. With the method MT, a measurer 82 shown in FIG. 15B may be used. The measurer 82 is attached to a pick TP. The measurer 82 measures the thickness of a deposit on the edge ring UR. The measurer 82 may include an image sensor that captures an image of the edge ring UR, or may include another optical sensor that measures the thickness of the deposit on the edge ring UR.

[0090] The controller 2 may determine, based on the thickness of the deposit on the edge ring UR measured with the measurer 82, whether the density of the plasma above the edge ring UR is to be increased. In one or more embodiments, the plasma processing based on the recipe includes cleaning of the

[0124] The plasma processing apparatus according to E11, further comprising a controller configured to control the switch to establish the first state or the second state based on a read recipe.

[E16]

[0125] The plasma processing apparatus according to E11, further comprising:

a measurer configured to measure a depth of etching on the substrate on the substrate support; and

a controller configured to control the switch to switch the second state to the first state in response to the depth of etching measured by the measurer reaching a threshold.

[E17]

[0126] A substrate processing system comprising:

the plasma processing apparatus according to E10;

a transfer module including a transfer chamber and a transfer robot connected to the plasma processing apparatus;

a ring stocker configured to store the upper edge ring or the upper edge ring and the set of rings; and

a controller configured to control the other lifter and the transfer robot to replace the upper edge ring or the set of rings in the chamber in the plasma processing apparatus with the upper edge ring or the set of rings in the ring stocker through the transfer chamber.

[E18]

[0127] A substrate processing system, comprising:

the plasma processing apparatus according to E11;

an imaging device configured to capture an image of a substrate etched by the plasma processing apparatus; and

a controller configured to control, in response to an image of a previously processed substrate having a roundness of a hole in an edge area of the substrate being less than or equal to a threshold, the switch to establish the first state to perform etching on a following substrate in the plasma processing apparatus.

[E19]

[0128] A substrate processing system, comprising:

WHAT IS CLAIMED IS:

1. A plasma processing apparatus, comprising:

a chamber;

a substrate support in the chamber;

an edge ring to surround a substrate on the substrate support, the edge ring being conductive;

a lifter configured to raise and lower the edge ring;

a plasma generator including a radio-frequency power supply, the plasma generator being configured to generate plasma in the chamber; and

a bias power supply configured to generate an electrical bias to draw ions from the plasma into the substrate on the substrate support,

wherein the substrate support comprises:

a base electrically coupled to at least one of the bias power supply or the radio-frequency power supply; and

an electrostatic chuck on the base, and

wherein the lifter comprises:

a conductive ring configured to be electrically coupled to the edge ring while supporting the edge ring that is disposed on the conductive ring;

a rod extending in a vertical direction below the conductive ring,

an actuator configured to raise and lower the edge ring with the rod and the conductive ring; and

a connector configured to electrically couple the conductive ring and the base, the connector being configured to maintain electrical coupling between the conductive ring and the base for movement of the conductive ring.

2. The plasma processing apparatus according to Claim 1, wherein the connector is deformable in response to movement of the conductive ring.

3. The plasma processing apparatus according to Claim 2, wherein the connector comprises a

bellows, a contact band, or a cylindrical member having a plurality of slits on a sidewall surface of the cylindrical member to be elastically deformable in a longitudinal direction of the cylindrical member.

4. The plasma processing apparatus according to any one of claims 1 to 3, wherein the rod is insulating.

5. The plasma processing apparatus according to any one of claims 1 to 3, wherein a surface of the conductive ring has an exposed area covered with a film resistant to the plasma.

6. The plasma processing apparatus according to any one of claims 1 to 3, wherein the edge ring is an upper edge ring,

wherein the plasma processing apparatus further comprises a lower edge ring on which the upper edge ring is located,

wherein the electrostatic chuck comprises:

a first portion including a substrate support surface; and

a second portion extending outside the first portion and having a ring support surface extending below the substrate support surface, and

wherein the first portion comprising:

a sidewall surface extending between the substrate support surface and the ring support surface, and

the lower edge ring is located on the ring support surface along the sidewall surface.

7. The plasma processing apparatus according to Claim 6, wherein the lower edge ring comprises:

an inner circumferential portion along the sidewall surface;

an outer circumferential portion extending radially outward from the inner circumferential portion, the upper edge ring being located on the outer circumferential portion; and

an intermediate portion extending between the inner circumferential portion and the outer

circumferential portion, the intermediate portion being located between an edge of the substrate on the substrate support surface and an inner circumferential surface of the upper edge ring.

8. The plasma processing apparatus according to Claim 6, wherein the lower edge ring is conductive.

9. The plasma processing apparatus according to Claim 6, wherein the lower edge ring is insulating.

10. The plasma processing apparatus according to Claim 6, further comprising another lifter configured to raise, from the electrostatic chuck, the upper edge ring or a set of rings including the upper edge ring and the lower edge ring.

11. The plasma processing apparatus according to any one of claims 1 to 3, further comprising a switch configured to change between establishing a first state in which the edge ring and the base are electrically coupled to each other and a second state in which the edge ring and the base are electrically disconnected from each other.

12. The plasma processing apparatus according to Claim 11, wherein the lifter is the switch configured to establish the second state by lowering the conductive ring with the actuator to separate the conductive ring from the edge ring.

13. The plasma processing apparatus according to Claim 11, wherein the switch includes a switching element connected between the connector and the conductive ring or between the connector and the base.

14. The plasma processing apparatus according to Claim 11, wherein the switch includes another lifter configured to establish the second state by raising the edge ring from the conductive ring.

15. The plasma processing apparatus according to Claim 11, further comprising a controller configured to control the switch to change to the first state or the second state based on a read recipe.

16. The plasma processing apparatus according to Claim 11, further comprising:

a measurer configured to measure a depth of etching on the substrate on the substrate support; and

a controller configured to control the switch to switch the second state to the first state in response to the depth of etching measured by the measurer reaching a threshold.

17. A substrate processing system, comprising:

the plasma processing apparatus according to Claim 10;

a transfer module including a transfer chamber and a transfer robot connected to the plasma processing apparatus;

a ring stocker configured to store the upper edge ring or the upper edge ring and the set of rings; and

a controller configured to control the other lifter and the transfer robot to replace the upper edge ring or the set of rings in the chamber in the plasma processing apparatus with the upper edge ring or the set of rings in the ring stocker through the transfer chamber.

18. A substrate processing system, comprising:

the plasma processing apparatus according to Claim 11;

an imaging device configured to capture an image of a substrate etched by the plasma processing apparatus; and

a controller configured to control, in response to an image of a previously processed substrate having a roundness of a hole in an edge area of the substrate being less than or equal to a threshold, the switch to establish the first state to perform etching on a following substrate in the plasma processing apparatus.

19. A substrate processing system, comprising:

the plasma processing apparatus according to Claim 11;

a measurer configured to measure a thickness of a deposit on the edge ring; and

a controller configured to control, during cleaning of the chamber, the switch to change to the second state in response to the thickness of the deposit being less than a threshold and to change to the first state in response to the thickness of the deposit being greater than or equal to the threshold.