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Plasma processing apparatus and plasma processing method

Abstract

A plasma processing apparatus includes a plasma processing chamber; a base; an electrostatic chuck; a plurality of electrode layers disposed in the same plane within the electrostatic chuck; a switch group including a plurality of first switches electrically connected to the electrode layers, respectively; a power supply and a measurement unit that are electrically connected to the switch group; a second switch that selects either the power supply or the measurement unit as a connection destination of the switch group; and a controller. The power supply includes a power source that supplies a power to the electrode layers. The measurement unit includes a resistor and a voltmeter that measures a voltage applied to the resistor. The controller is capable of executing a control operation that includes switching the connection destination of the switch group to the measurement unit and then turning ON the plurality of first switches one by one.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) The present application is based on and claims priority from Japanese Patent Application No. 2022-104289, filed on Jun. 29, 2022, with the Japan Patent Office, the disclosure of which is incorporated herein in its entirety by reference.

TECHNICAL FIELD

(2) The present disclosure relates to a plasma processing apparatus and a plasma processing method.

BACKGROUND

(3) U.S. Pat. No. 9,601,301 discloses a method of applying a voltage to an electrode used for clamping a substrate embedded into an electrostatic chuck and determining a self-bias voltage V.sub.dc on the basis of the resulting current flowing through the electrode.

SUMMARY

(4) According to an aspect of the present disclosure, a plasma processing apparatus includes a plasma processing chamber; a base disposed in the plasma processing chamber; an electrostatic chuck disposed on top of the base; a plurality of electrode layers disposed in the same plane within the electrostatic chuck; a switch group including a plurality of first switches electrically connected

to the plurality of electrode layers, respectively; a power supply and a measurement unit that are electrically connected to the switch group; a second switch configured to select either the power supply or the measurement unit as a connection destination of the switch group; and a controller. The power supply includes a power source that supplies a power to the plurality of electrode layers. The measurement unit includes a resistor and a voltmeter that measures a voltage applied to the resistor. The controller is capable of executing a control operation that includes switching the connection destination of the switch group to the measurement unit and then turning ON the plurality of first switches constituting the switch group one by one.
(5) The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a diagram illustrating an exemplary configuration of a plasma processing system according to an embodiment.
(2) FIG. **2** is a cross-sectional view illustrating an exemplary configuration of a plasma processing apparatus according to an embodiment.
(3) FIG. **3** is a graph illustrating the relationship between a bias voltage, self-bias voltage, and bias RF signal.
(4) FIG. **4** is a top plan view schematically illustrating segmented regions of an electrostatic chuck according to an embodiment.
(5) FIG. **5** is a cross-sectional view schematically illustrating electrical connection in a substrate support according to an embodiment.
(6) FIG. **6** is a sequence diagram illustrating an overview of a plasma processing method according to an embodiment.
(7) FIG. **7** is a flowchart illustrating an overview of the plasma processing method according to an embodiment.
(8) FIG. **8** is a cross-sectional view schematically illustrating the electrical relationship between a substrate, a ceramic member, and a heater element in the plasma processing method according to an embodiment.
(9) FIG. **9** is an equivalent circuit diagram schematically illustrating the electrical relationship between a substrate and a substrate support in the plasma processing method according to an embodiment.
DETAILED DESCRIPTION
(10) In the following detailed description, reference is made to the accompanying drawings, which form a part thereof. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made without departing from the spirit or scope of the subject matter presented here.
(11) In the semiconductor device manufacturing process, various plasma processing processes are performed to generate plasma from a desired processing gas in a processing module in which a semiconductor wafer (hereinafter referred to as “substrate”) is accommodated therein to perform a desired processing on the substrate using the plasma. With the miniaturization of semiconductor devices, a plasma processing that achieves a high aspect ratio becomes more important. In order to achieve a high aspect ratio, a method of increasing the ion energy by increasing the bias voltage of a substrate support has been proposed. However, increasing the bias voltage may raise the likelihood of the occurrence of arcing, even leading to impairment of plasma stability and

uniformity. Thus, to prevent arching and enhance plasma stability and uniformity, it is desirable to control a bias voltage by continuously detecting a self-bias voltage included in a bias voltage. Further, it is desirable to measure the in-plane distribution of the self-bias voltage to predict the distribution of etching characteristics.
(12) In order to solve such problems, a method has been proposed in the related art, in which an electrode is provided inside the electrostatic chuck and the self-bias voltage is constantly monitored by measuring the voltage applied to the electrode. Further, U.S. Pat. No. 9,601,301 discloses a technique that applies a voltage to an electrode used for clamping and calculates a self-bias voltage on the basis of the resulting current flowing through the electrode.
(13) However, according to the method in the related art, it is necessary to change the design to incorporate an additional electrode inside the electrostatic chuck. Such a design change for an existing apparatus is difficult in terms of affecting the temperature adjustment by a heater or a heat transfer medium. Further, U.S. Pat. No. 9,601,301 does not disclose a technique for measuring the in-plane distribution of the self-bias voltage, nor does it suggest predicting an in-plane distribution of etching characteristics.
(14) Thus, the technology according to the present disclosure measures an in-plane distribution of a self-bias voltage of a substrate support. Specifically, the technology has an exemplary configuration with a heater electrode layer including a plurality of heater elements inside an electrostatic chuck of a substrate support and a measurement unit that measures the voltage of each heater element. The technology performs an operation of measuring the voltage for each heater element and calculating a self-bias voltage in respective regions of the substrate support that correspond to respective heater elements on the basis of the measured voltage.
(15) Hereinafter, a configuration of a plasma processing apparatus according to the present embodiment will be described with reference to the drawings. The same reference numerals are herein used to indicate the same functional components and repetitive descriptions may be omitted for brevity.
(16) <Plasma Processing System>
(17) FIG. **1** is a diagram illustrating an exemplary configuration of a plasma processing system. In one embodiment, 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, and 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 also has at least one gas supply port for delivering at least one processing gas into the plasma processing space and at least one gas discharge port for exhausting gas from the plasma processing space. The gas supply port is connected to a gas-supplying unit **20**, which will be described later, while the gas discharge port is connected to an exhaust system **40**, which will be described later. The substrate support **11** is disposed inside the plasma processing space and has a substrate-supporting surface used for supporting the substrate.
(18) The plasma generator **12** generates plasma from at least one processing gas supplied into the plasma processing space. Examples of plasma that may be generated in the plasma processing space include capacitively coupled plasma (CCP), inductively coupled plasma (ICP), electron cyclotron resonance (ECR) plasma, helicon wave excited plasma (HWP), surface wave plasma (SWP), or other forms of plasma. Further, the plasma generator may be of various types, such as an alternating current (AC) plasma generator and a direct current (DC) plasma generator. In one specific embodiment, the AC plasma generator uses an AC signal (AC power) with a frequency ranging from 100 kHz to 10 GHz. Thus, the AC signal includes radio frequency (RF) signals and microwave signals. In one embodiment, the RF signal has a frequency within the range of 100 kHz to 150 MHz.
(19) The controller **2** processes computer-executable instructions, which cause the plasma

processing apparatus **1** to perform various processing described in the present disclosure. The controller **2** is capable of controlling the respective components of the plasma processing apparatus **1**, enabling the components to perform various processing described herein. In one specific embodiment, the entirety or a part of the controller **2** may be included in the plasma processing apparatus **1**. The controller **2** may include a processor **2***a***1**, a storage unit **2***a***2**, and a communication interface **2***a***3**. The controller **2** is implemented by, for example, a computer **2***a*. The processor **2***a***1** may read and execute a program from the storage unit **2***a***2**, enabling the performance of various control operations. The program may be pre-stored in the storage unit **2***a***2** or retrieved from a medium as needed. Once retrieved, the program is stored in the storage unit **2***a***2** and then loaded from the storage unit **2***a***2** by the processor **2***a***1** for execution. Examples of the medium include various storage media that are readable by the computer **2***a* and a communication line that may be connected to the communication interface **2***a***3**. The processor **2***a***1** may be a central processing unit (CPU). The storage unit **2***a***2** may include random-access memory (RAM), read-only memory (ROM), hard disk drive (HDD), solid-state drive (SSD), or a combination thereof. The communication interface **2***a***3** may facilitate communication with the plasma processing apparatus **1** over a communication line such as a local area network (LAN).
(20) <Plasma Processing Apparatus>
(21) Hereinafter, descriptions will be made on an exemplary configuration of a capacitively coupled plasma processing apparatus as an example of the plasma processing apparatus **1**. FIG. **2** is a diagram illustrating an exemplary configuration of the capacitively coupled plasma processing apparatus **1**.
(22) The capacitively coupled plasma processing apparatus **1** includes a plasma processing chamber **10**, a gas-supplying unit **20**, a power source **30**, and an exhaust system **40**. Further, the plasma processing apparatus **1** includes a gas inlet and a substrate support **11**. The gas inlet introduces at least one processing gas into the plasma processing chamber **10**. The gas inlet includes a showerhead **13**. The substrate support **11** is disposed in the plasma processing chamber **10**. The showerhead **13** is disposed above the substrate support **11**. In one specific embodiment, the showerhead **13** forms at least a portion of the ceiling of the plasma processing chamber **10**. The plasma processing chamber **10** has a plasma processing space **10***s* that is defined by the showerhead **13**, a side wall **10***a* of the plasma processing chamber **10**, and the substrate support **11**. The plasma processing chamber **10** is grounded, while the showerhead **13** and the substrate support **11** are electrically insulated from the housing of the plasma processing chamber **10**.
(23) The substrate support **11** includes a body portion **50** and a ring assembly **52**. The body portion **50** has a central region **50***a*, which supports a substrate W, and an annular region **50***b*, which supports the ring assembly **52**. An example of the substrate W is a wafer. In plan view, the annular region **50***b* of the body portion **50** encircles the central region **50***a* of the body portion **50**. The substrate W is disposed on the central region **50***a* of the body portion **50**. The ring assembly **52** is disposed on the annular region **50***b* of the body portion **50** to encircle the substrate W disposed on the central region **50***a* of the body portion **50**. Thus, the central region **50***a* is also referred to as a substrate-supporting surface used for supporting the substrate W, while the annular region is also referred to as a ring-supporting surface used for supporting the ring assembly **52**.
(24) In one embodiment, the body portion **50** includes a base **60** and an electrostatic chuck **62**. The base **60** includes a conductive member. The conductive member of the base **60** may function as a lower electrode. The electrostatic chuck **62** is disposed on the base **60**. The electrostatic chuck **62** includes a ceramic member **64**, a clamping electrode layer **66** disposed inside the ceramic member **64**, and a heater electrode layer **68**. The heater electrode layer **68** is disposed on top of the clamping electrode layer **66**. The heater electrode layer **68** will be described in detail later. The ceramic member **64** has the central region **50***a*. In one specific embodiment, the ceramic member **64** also has the annular region **50***b*. The annular region **50***b* may be included in another member that encircles the electrostatic chuck **62**, such as an annular electrostatic chuck or an annular insulating

member. In this configuration, the ring assembly **52** may be disposed on either the annular electrostatic chuck or the annular insulating member, or on both the electrostatic chuck **62** and the annular insulating member. Furthermore, at least one RF-DC electrode coupled to an RF power source **31** and/or a DC power source **32**, as described later, may be disposed inside the ceramic member **64**. In this case, at least one RF-DC electrode functions as a lower electrode. When a bias RF signal and/or a DC signal, as described later, is applied to at least one RF-DC electrode, the RF-DC electrode is also referred to as a bias electrode. The conductive member of the base **60** and at least one RF-DC electrode may function as multiple lower electrodes. Alternatively, the clamping electrode layer **66** may function as a lower electrode. Consequently, the substrate support **11** includes at least one lower electrode.

(25) The ring assembly **52** includes one or more annular members, which, in a specific embodiment, have one or more edge rings and at least one cover ring. The edge ring is made of a conductive or insulating material, while the cover ring is made of an insulating material.

(26) Further, the substrate support **11** includes a temperature regulation module, which controls the temperature of at least one of the electrostatic chuck **62**, the ring assembly **52**, or the substrate W to a target temperature. The temperature regulation module may include the heater electrode layer **68**, heat transfer medium, a flow path **70**, or combinations thereof. Heat transfer fluids, like brine or gas, flow through the flow path **70**. In one specific embodiment, the flow path **70** is formed inside the base **60**. Furthermore, the substrate support **11** may include a heat transfer gas-supplying unit that supplies the gap between the back surface of the substrate W and the central region **50***a* with a heat transfer gas.

(27) The showerhead **13** introduces at least one processing gas from the gas-supplying unit **20** into the plasma processing space **10***s*. The showerhead **13** has at least one gas supply port **13***a*, at least one gas diffusion chamber **13***b*, and a plurality of gas introduction ports **13***c*. The processing gas supplied to the gas supply port **13***a* flows through the gas diffusion chamber **13***b* and enters the plasma processing space **10***s* via the multiple gas introduction ports **13***c*. Further, the showerhead **13** also includes at least one upper electrode. The gas inlet may include one or more side gas injectors (SGIs) attached to one or more openings formed in the side wall **10***a*, in addition to the showerhead **13**.

(28) The gas-supplying unit **20** may include at least one gas source **21** and at least one flow controller **22**. In one embodiment, the gas-supplying unit **20** delivers at least one processing gas to the showerhead **13** from the corresponding gas sources **21** through the corresponding flow controllers **22**. The flow controllers **22** may each include, for example, a mass flow controller or a pressure-controlled flow controller. Further, the gas-supplying unit **20** may further include at least one flow modulation device used to modulate or pulse the flow rate of at least one processing gas.

(29) The power source **30** includes an RF power source **31** that is coupled to the plasma processing chamber **10** via at least one impedance-matching circuit. The RF power source **31** supplies at least one lower electrode and/or at least one upper electrode with at least one RF signal (or RF power). This configuration allows the production of plasma from at least one processing gas supplied to the plasma processing space **10***s*. Thus, the RF power source **31** may function as at least a part of the plasma generator **12**. Furthermore, supplying a bias RF signal to at least one lower electrode enables the generation of a bias voltage V.sub.B in the substrate W, which draws ion components in the produced plasma into the substrate W. The bias voltage V.sub.B will be described in detail later.

(30) In one embodiment, the RF power source **31** includes a first RF generator **31***a* and a second RF generator **31***b*. The first RF generator **31***a* is coupled to at least one lower electrode and/or at least one upper electrode via at least one impedance-matching circuit to generate a source RF signal (or source RF power) for plasma production. In one specific embodiment, the source RF signal has a frequency within the range of 10 MHz to 150 MHz. In one specific embodiment, the first RF generator **31***a* may generate multiple source RF signals with different frequencies. The generated one or more source RF signals are delivered to at least one lower electrode and/or at least one

one upper electrode.
(31) The second RF generator **31***b* is coupled to at least one lower electrode via at least one impedance-matching circuit to generate the bias RF signal (or bias RF power). The frequency of the bias RF signal may be the same as or different from the frequency of the source RF signal. In one embodiment, the bias RF signal has a frequency lower than the frequency of the source RF signal. In one specific embodiment, the bias RF signal has a frequency within the range of 100 kHz to 60 MHz. In one specific embodiment, the second RF generator **31***b* may generate multiple bias RF signals with different frequencies. The generated one or more bias RF signals are delivered to at least one lower electrode. Further, in some embodiments, at least one of the source RF signal and the bias RF signal may be pulsed.
(32) Further, the power source **30** may include a direct current (DC) power source **32** that is coupled to the plasma processing chamber **10**. The DC power source **32** includes a first DC generator **32***a* and a second DC generator **32***b*. In one embodiment, the first DC generator **32***a* is connected to at least one lower electrode to generate a first DC signal. The generated first DC signal is applied to at least one lower electrode. In one specific embodiment, the second DC generator **32***b* is connected to at least one upper electrode to generate a second DC signal. The generated second DC signal is applied to at least one upper electrode.
(33) In various embodiments, the first and second DC signals may be pulsed, in which case a sequence of voltage pulses is applied to at least one lower electrode and/or at least one upper electrode. The voltage pulses may have pulse waveforms such as rectangular, trapezoidal, triangular, or combinations thereof. In one embodiment, a waveform generator, which generates a sequence of voltage pulses from the DC signal, may be connected between the first DC generator **32***a* and at least one lower electrode. Thus, the first DC generator **32***a* and the waveform generator constitute a voltage pulse generator. When the second DC generator **32***b* and the waveform generator constitute the voltage pulse generator, the voltage pulse generator may be connected to at least one upper electrode. The voltage pulse may have either a positive or negative polarity. Further, the sequence of voltage pulses may include one or more positive voltage pulses and one or more negative voltage pulses in one cycle. The first and second DC generators **32***a* and **32***b* may be provided in addition to the RF power source **31**, and the first DC generator **32***a* may be provided instead of the second RF generator **31***b*.
(34) Here, a self-bias voltage V.sub.dc generated in the substrate support **11** will be described. As previously described, in the case where the plasma processing apparatus **1** is supplied with the source RF signal, the gas introduced into the plasma processing space **10***s* is ionized into electrons and positive ions, producing the plasma PM. During this process, electrons, which have a small mass, move in the plasma processing space **10***s* following the variations in high-frequency voltages of the source RF signal and flow into the lower electrode, which is the substrate support **11**. Meanwhile, the positive ions, with their larger mass, are unable to respond to the variations in high-frequency voltages of the source RF signal, causing most of them to remain in the plasma processing space **10***s*. This results in the substrate support **11** being negatively charged relative to the plasma processing space **10***s*. The voltage of the substrate support **11** in this condition is referred to as the self-bias voltage V.sub.dc.
(35) In one embodiment, the bias RF signal is supplied to the lower electrode. FIG. **3** is a graph illustrating an example of the variation in the bias voltage V.sub.B over time during the application of the bias RF signal. The solid line represents the bias voltage V.sub.B, the dotted line represents the self-bias voltage V.sub.dc, and the alternating long and short dashed line represents a bias RF signal voltage V.sub.rf. In the example of FIG. **3**, the bias voltage V.sub.B equals the sum of the self-bias voltage V.sub.dc and the bias RF signal voltage V.sub.rf. In other words, the graph of the bias voltage V.sub.B may be obtained by offsetting the graph of the bias RF signal voltage V.sub.rf by the self-bias voltage V.sub.dc in the negative direction.
(36) The exhaust system **40** may be connected to, for example, a gas discharge port that is provided

at the bottom of the plasma processing chamber **10**. The exhaust system **40** may include a pressure regulating valve and a vacuum pump. The pressure regulating valve controls the pressure in the plasma processing space **10***s*. The vacuum pumps may include turbomolecular pumps, dry pumps, or a combination of both.

(37) Next, the body portion **50** of the substrate support **11** will be described in detail. FIG. **4** is a top plan view illustrating an overview of the structure of the body portion **50** in the substrate support **11** according to the present embodiment.

(38) In FIG. **4**, only the electrostatic chuck **62** is depicted of the main body **50** in the substrate support **11**. The electrostatic chuck **62** in the body portion **50** includes the central region **50***a* and the annular region **50***b*, as previously described. The central region **50***a* is surrounded by the inner circle of circles represented by solid lines, and the annular region **50***b* is sandwiched between the inner and outer circles of circles represented by solid lines.

(39) The central region **50***a* and the annular region **50***b* are segmented into multiple regions, one of which is called a segmented region **80**. In the figure, the central region **50***a* and the annular region **50***b* are radially segmented by straight lines and concentric circles represented by the alternating long and short dashed lines. The hatched portion represents one of the segmented regions **80**, which are segmented as described above. All of the regions segmented in the same way as the manner described above are segmented regions **80**, like the hatched region **80**, but their hatching and reference numerals are omitted for clarity. Moreover, such segmentation is made for convenience only and does not imply physical separation. The segmented regions **80** are provided with their respective corresponding heater elements **100**, which are multiple heater electrode layers included in the heater electrode layer **68**. Moreover, each of the multiple heater electrode layers included in the heater electrode layer **68** is herein referred to as the heater element **100** to avoid duplication of component naming. In the figure, the segmented region **80**, which is represented by hatching, is provided with one corresponding heater element **100**, which is represented by dotted lines. Each of the multiple heater elements **100** is one of the electrodes that form part of the heater electrode layer **68**. Furthermore, the multiple heater elements **100** are embedded in the electrostatic chuck **62** near their respective corresponding segmented regions **80** and are all provided in the same plane. The multiple heater elements **100** are supplied with alternating current (AC) to heat their respective corresponding segmented regions **80**. In the figure, only one of the multiple heater elements **100** is depicted, and other heater elements **100** corresponding to other segmented regions **80** are omitted for clarity, as they are identical. The segmented region **80** may have shapes other than the example illustrated in the figure. Both the central region **50***a* and the annular region **50***b* may be segmented into a plurality of regions with different shapes. In this case, only the central region **50***a* may be segmented into a plurality of regions, and the annular region **50***b* may be segmented into a plurality of regions with an undivided shape. Further, the shape of the heater element **100** is not limited to the example illustrated in the figure. The heater elements **100** may have a shape and quantity that corresponds to the segmented region **80**.

(40) FIG. **5** is a cross-sectional view of a part of the plasma processing apparatus **1**, illustrating the overview of the configuration of electrical connections in the substrate support **11**. However, for the sake of clarity, any illustrations of the configuration that is unnecessary for the description of the electrical connection in the substrate support **11** are omitted. The phrase "electrical connection" as used herein refers to the connection of one component to another component to form an electric circuit. This connection may be made via a conductor such as a wire, or it may be made wirelessly by coupling an electric field or a magnetic field. The connection may be established directly, meaning that there are no other components between the connected components, or indirectly, signifying that there are other components between the connected components. In some cases, the electrical connection may be simply referred to as "connected" without the use of the term "electrical." In addition, the condition where one component is electrically connected to another component is defined as the "on" state for the other component, while the condition where one

component is not connected is similarly defined as the “off” state. Further, for a component with a connection state that may be switched on or off using a switch described later, the state of the switch that turns on the component is defined as the “on” state of the switch, while the state of the switch that turns off the component is defined as the “off” state of the switch.

(41) In FIG. **5**, the multiple heater elements **100** are electrically connected individually to a power supply **104** or a measurement unit **106** via a switch group that includes a plurality of first switches **102**. The first switches **102** are capable of switching on or off the connection of their respective corresponding heater elements **100** to the power supply **104** or the measurement unit **106**. In the example of FIG. **5**, only the first switch associated with the heater element **100** illustrated on the far right is turned on, while the first switches associated with all other heater elements **100** are turned off. The first switches **102** allow for turning on or off all of the heater elements **100** and, furthermore, allow for turning on a predetermined number of heater elements **100** among the plurality of heater elements **100** while turning off the remaining ones. Specifically, the first switch **102** may be a relay that is capable of being controlled by the controller **2** to switch on or off using an electric signal.

(42) The power supply **104** and the measurement unit **106** are electrically connected to the plurality of heater elements **100** via a second switch **110**. The second switch **110** is capable of switching on or off the connection of the power supply **104** and the measurement unit **106** to the multiple heater elements **100**. In other words, the second switch selects one of the power supply **104** or the measurement unit **106** as the connection destination for the plurality of first switches and switches the connection to the selected one. The second switch **110** allows for switching between turning on the power supply **104** and turning off the measurement unit **106**, between turning off the power supply **104** and turning on the measurement unit **106**, or between turning off both units simultaneously. In the example of FIG. **5**, both the power supply **104** and the measurement unit **106** are off, that is, in a floating state. Specifically, the second switch **110** may be a relay that is capable of being controlled by the controller **2** to switch on or off using an electric signal.

(43) In one example, there may be provided a configuration where all of the first switches **102** are simultaneously turned on, while the second switch **110** turns on the power supply **104** and turn off the measurement unit **106**. This configuration enables the first switches **102** and the second switches **110** to connect all of the heater elements **100** to the power supply **104**. Further, in one example, a configuration may also be provided, in which only one of the first switches **102** is turned on, all the other remaining first switches **102** are turned off, the second switch **110** turns on the measurement unit **106**, and turns off the power supply **104**. This configuration makes it possible to connect only one of the heater elements **100** to the measurement unit **106**. In addition to the configurations described above, it is possible to connect any one or all of the heater elements **100** to any desired combination of either the power supply **104** or the measurement unit **106**.

(44) The power supply **104** includes a heater power source **120**, which delivers electric power to the heater electrode layer **68**, and a heater control panel **122**. The heater control panel **122** controls power feeding supplied from the heater power source **120**. In one example, the controller **2** may control the heater control panel **122** using an electrical signal, allowing it to control power feeding supplied from the heater power source **120**.

(45) There is provided an RF filter **124** between the power supply **104** and the plurality of first switches **102**. During plasma production, RF noise originating from high-frequency power supplied from the RF power source **31** may sometimes enter the power supply **104** through the heater electrode layer **68**. The RF noise that reaches the heater power source **120** may impair its operation or performance of the heater power source **120** or cause high-frequency power consumption in the heater electrode layer **68**, which may lead to a reduction in the efficiency of plasma production. The RF filter **124** is responsible for attenuating or blocking such RF noise to protect the power supply **104**. Thus, any known filter capable of attenuating or blocking an alternating current at a predetermined frequency may be used as the RF filter **124**. Specifically, examples of such filters

may include a coil, a capacitor or a resistor, or a combination thereof.
(46) The measurement unit **106** includes the RF filter **124**, a resistor **130**, and a voltmeter **132** that measures the voltage applied to the resistor **130**. In the measurement unit **106**, the RF filter **124** removes the impact of RF noise from the voltage measured by the voltmeter **132**. In other words, the voltmeter **132** may measure a voltage from which RF noise has been removed. In addition, the measurement unit **106** is capable of transmitting the voltage measured by the voltmeter **132** to the controller **2** and recording the value of the voltage.
(47) <Plasma Processing Method>
(48) Next, descriptions will be made on a plasma processing method MT that is implementable in the plasma processing apparatus **1** described above. In the plasma processing method MT, the self-bias voltage V.sub.dc of the substrate support **11** upon plasma production is calculated for each of the segmented regions **80**. Specifically, steps ST**1** to ST**9** described below are executed sequentially to connect the heater elements **100** corresponding to the respective segmented regions **80** to the measurement unit **106** one by one, causing it to measure a voltage V.sub.2 for each of the heater elements **100**. Subsequently, step ST**10** performs the operation on the basis of the voltage V.sub.2 to calculate the self-bias voltage V.sub.dc in the segmented region **80**. FIGS. **6** and **7** illustrate an example of the processing procedure of the plasma processing method MT according to the present embodiment in the form of a sequence diagram (FIG. **6**) and a flowchart (FIG. **7**).
(49) In FIG. **6**, in part (a), “on” or “off” refers to whether or not the RF power is supplied from the RF power source **31** in a time series. In part (b), “on” or “off” refers to whether or not power is supplied to the clamping electrode layer **66**, which acts as the lower electrode in a time series. In part (c), “all on,” “only one on,” or “all off” refers to whether the first switches **102** are turned on or off in a time series. In part (d), “power supply on,” “measurement unit on,” or “floating” refers to the state where the power supply **104** or the measurement unit **106** is turned on or both are turned off (floating) by the second switch in a time series. When the power supply **104** is turned on, the measurement unit **106** is turned off, and vice versa when the measurement unit **106** is on, the power supply **104** is turned off.
(50) In FIGS. **6** and **7**, the plasma processing method MT starts with the following initial states: no RF power is supplied, no power is supplied to the clamping electrode layer **66**, the first switches **102** are all off, and the second switch **110** is in a floating state. Moreover, upon the start, it is assumed that the substrate W is loaded into the plasma processing chamber **10** in advance and disposed on the substrate support **11**.
(51) In step ST**1**, a specific gas for plasma production is introduced, and subsequently the RF power is supplied. The RF power includes at least a source RF signal for plasma production, producing plasma PM in the plasma processing space **10***s*. Furthermore, the RF power may also include a bias RF signal that attracts plasma ions towards the substrate W. The bias RF signal may be supplied prior to, after, or simultaneously with the application of the source RF signal.
(52) In step ST**2**, power is supplied to the clamping electrode layer **66**. This causes the substrate W to be attracted to an upper surface **62***a* of the electrostatic chuck **62**. Once the substrate W is attracted, a heat transfer medium may be supplied to the gap between the back surface of the substrate W and the central region **50***a*.
(53) In step ST**3**, power is supplied to the heater electrode layer **68**. Specifically, the first switches **102** are all turned on, and the power supply **104** is turned on through the second switch **110**. This enables the connection of all the heater elements **100** to the power supply **104**, allowing alternating current (AC) power to be supplied from the heater power source **120** to all the heater elements **100**.
(54) In step ST**4**, one of the heater elements **100** is turned on, and its voltage V.sub.2 is measured by the measurement unit **106**. Specifically, among the plurality of first switches **102** all turned on in step ST**3**, only one intended first switch remains on, while all other first switches **102** are turned off. Simultaneously, the measurement unit **106** is turned on through the second switch **110**. This causes only one heater element **100** corresponding to the first switch **102** turned on to be connected

to the measurement unit **106**. In the measurement unit **106**, the voltmeter **132** measures the voltage V.sub.2 applied to the resistor **130**.

(55) In step ST**5**, power is supplied to the heater electrode layer **68**. Specifically, this step is similar to step ST**3**.

(56) In step ST**6**, one of the heater elements **100** for which voltage has not been measured is turned on, and the voltage V.sub.2 is measured in the measurement unit **106**. The one heater element **100** for which voltage has not been measured is the heater element **100** other than the one heater element **100** for which the voltage V.sub.2 has been measured in step ST**4** and specifically, is the heater element **100** for which the voltage V.sub.2 has not yet been measured even in the case where step ST**6** is repeatedly performed, as will be described later. In step ST**6**, only the first switch **102** corresponding to the one heater element **100** for which voltage has not been measured is turned on, while all the other first switches **102** are turned off. Simultaneously, the measurement unit **106** is turned on through the second switch **110**. This allows only one heater element **100**, which has not had its voltage measured, to be connected to the measurement unit **106**. In the measurement unit **106**, the voltage V.sub.2 applied to the resistor **130** is measured by the voltmeter **132**. The heater element **100** for which the voltage V.sub.2 has been measured in step ST**6** is not included in the heater element **100**, which has not had its voltage measured.

(57) After step ST**6**, it is determined whether the voltage measurement for all the heater elements **100** is completed. When the voltage measurement for all the heater elements **100** is not completed, and thus, there are one or more heater elements **100** for which voltage measurement is not performed, steps ST**5** and ST**6** are then performed again. This causes step ST**6** to be repeatedly performed, which reduces the number of the heater elements **100** with unmeasured voltage. When the voltage measurement is finally completed for all the heater elements **100** and there is no heater element **100** with unmeasured voltage, then the process proceeds to step ST**7**.

(58) In step ST**7**, all the heater elements **100** are turned off through the first switch **102**, and the power supply **104** and the measurement unit **106** are both turned off (floating) through the second switch **110**.

(59) In step ST**8**, the supply of RF power is terminated. In step ST**9**, static electricity is eliminated from the surface of the electrostatic chuck **62** and the substrate W, and then the supply of power to the clamping electrode layer **66** is terminated.

(60) In step ST**10**, the operation is performed to calculate the self-bias voltage V.sub.dc for each segmented region **80** on the basis of the voltage V.sub.2 measured for each heater element **100**. In the examples depicted in FIGS. **6** and **7**, step ST**10** is executed after step ST**9**, and the operations based on the voltage Vz measured for all the heater elements **100**, which is obtained in steps ST**4** and ST**6**, are collectively carried out, but are not limited to this exemplary procedure. In one instance, step ST**10** may be performed immediately after measuring the voltage Vz in steps ST**4** and ST**6**. The operation mentioned above may be performed in the controller **2** by causing the measurement unit **106** to transmit the value of the voltage V.sub.2 to the controller **2**.

(61) Hereinafter, descriptions will be made on an operation executed in step ST**10** with reference to FIGS. **8** and **9**. FIG. **8** is a cross-sectional view schematically illustrating the electrical relationship between the substrate W, the ceramic member **64**, and the heater element **100**, in steps ST**4** and ST**6**. FIG. **9** is an equivalent circuit for the substrate W and the substrate support **11** when the i-th heater element **100**, which will be described later, is turned on and the measurement unit **106** is turned on, in steps ST**4** and ST**6**.

(62) In FIG. **8**, parasitic capacitance exists both between the substrate W and the upper surface **62***a* of the electrostatic chuck **62** in the central region **50***a* and between the upper surface **62***a* and the heater element **100**. This capacitance may be considered as equivalent to a capacitive element. The capacitance between the substrate W and the upper surface **62***a* of the electrostatic chuck **62** is designated as C.sub.1, and the capacitance between the upper surface **62***a* of the electrostatic chuck **62** and the heater element **100** is designated as C.sub.2. In this regard, assuming that the number i

of the heater elements **100** is provided, the capacitance between the upper surface **62***a* of the electrostatic chuck **62** and the i-th heater element **100** is designated as C_{2i}. The capacitance values C_1 and C_{2i} may be calculated as fixed values on the basis of design parameters, including the area, length (distance), and dielectric constant of each component of the substrate W, the upper surface **62***a* of the electrostatic chuck **62**, the ceramic member **64**, and the heater element **100**.
(63) In FIG. **9**, the capacitance value C_1 and C_{2i} are the capacitances between the substrate W and the upper surface **62***a* of the electrostatic chuck **62** and between the upper surface **62***a* and the i-th heater element **100**, respectively, as illustrated in FIG. **8**. The capacitance of the RF filter **124** in the measurement unit **106** when it is considered equivalent to a capacitive element is designated as C_3. The resistance value of the resistor **130** is designated as R. The sum of voltages in the equivalent circuit is designated as V_0. The voltage across the substrate W and the heater electrode layer **68** is designated as V_1. The voltage measured by the voltmeter **132** in step ST**4** or ST**6** is designated as V_2. The charge accumulated across the substrate W and the upper surface **62***a* of the electrostatic chuck **62** is designated as Q_1. The charge accumulated across the upper surface **62***a* of the electrostatic chuck **62** and the i-th heater element **100** is designated as Q_{2i}. The charge accumulated in the RF filter **124** is designated as Q_3.
(64) The charges Q_1, Q_{2i}, and Q_3 in the equivalent circuit depicted in FIG. **9** satisfy the following relationship in accordance with the principle of charge conservation:
$$Q_1+Q_{2i}-Q_3=0$$
(65) This equation may be reformulated as:
$$Q_1+Q_{2i}=Q_3 \qquad (1)$$
(66) The charges Q_1, Q_{2i}, and Q_3, voltages V_1 and V_2, and capacitances C_1, C_{2i}, and C_3 in the equivalent circuit depicted in FIG. **9** satisfy the following relationships.
$$Q_1+Q_{2i}=(C_1+C_{2i})*V_1 \qquad (2)$$
$$Q_3=C_3*V_2 \qquad (3)$$
(67) By substituting Formulas (2) and (3) into Formula (1), Formula (4) for the relational expression between V_1 and V_2 is obtained as follows:
$$(C_1+C_{2i})*V_1=C_3*V_2$$
(68) This expression may be reformulated as:
$$V_1=C_3/(C_1+C_{2i})*V_2 \qquad (4)$$
(69) The voltage V_0 in the equivalent circuit depicted in FIG. **9** is the sum of the voltages V_1 and V_2, given by the following equation:
$$V_0=V_1+V_2$$
(70) By substituting Formula (4) into the above equation, the resulting equation is as follows:
$$V_0=C_3/(C_1+C_{2i})*V_2+V_2 \qquad (5)$$
(71) In this context, the voltage V_0 represents the voltage of the overall equivalent circuit depicted in FIG. **9** in the case where the i-th heater element **100** is turned on, and as well as it may be considered as the self-bias voltage V_{dc} of the segmented region **80** corresponding to the i-th heater element **100**. From this consideration and Formula (5), the resulting expression may be given as:
$$V_{dc}=C_3/(C_1+C_{2i})*V_2+V_2 \qquad (6)$$
(72) According to Formula (6), the self-bias voltage V_{dc} of the segmented region **80** corresponding to the i-th heater element **100** may be expressed using the voltage V_2 measured by the measurement unit **106**. In other words, in step ST**10**, the use of Formula (6) enables the computation of the self-bias voltage V_{dc} of the segmented region corresponding to the i-th heater element **100** on the basis of the voltage V_2.
(73) In steps ST**4** and ST**6**, the voltage V_2 is measured for all the heater elements **100** from the first to the i-th heater elements. Thus, in step ST**10**, the self-bias voltage V_{dc} may be

calculated for the respective segmented regions **80** corresponding to all the heater elements **100** from the first to the i-th heater elements.
(74) The preceding description gives the case where the i-th heater element **100** is the heater element **100** disposed in the central region **50***a* of the substrate support **11** facing the substrate W. Meanwhile, when the heater element **100** is located in the annular region **50***b* of the substrate support **11** facing the ring assembly **52**, the self-bias voltage V.sub.dc may be calculated as described below. In other words, as illustrated in FIG. **8**, the capacitance between the ring assembly **52** and the upper surface **62***b* of the electrostatic chuck **62** in the annular region **50***b* is designated as C.sub.1, the voltage between the ring assembly **52** and the heater electrode layer **68** is designated as V.sub.1, and the charge accumulated between the ring assembly **52** and the upper surface **62***b* of the electrostatic chuck **62** is designated as Q.sub.1. Based on these details, the operation of step ST**10** is executed.
(75) According to the preceding disclosure, it is possible to calculate the self-bias voltage V.sub.dc for each of the segmented regions **80** of the substrate support **11** on the basis of the voltage V.sub.2 measured for the respective heater elements **100**. This configuration enables the use of the substrate support **11** provided with the heater electrode layer **68** including the plurality of heater elements **100** inside the electrostatic chuck **62**, making it possible to measure the in-plane distribution of the self-bias voltage Vdc without necessitating any modifications to the internal structure of the electrostatic chuck **62**. Furthermore, the use of the in-plane distribution of the self-bias voltage Vdc makes it possible to predict the in-plane etching characteristics of the substrate W.
(76) Although the present embodiment exemplifies the substrate support **11** in the capacitively coupled plasma processing apparatus **1**, the configuration of the present disclosure is not limited to this specific exemplary arrangement. Similar effects may be attained by employing a similar configuration for the substrate support **11** in the inductively coupled plasma processing apparatus **1**.
(77) Furthermore, in one example, in steps ST**4** and ST**6**, the multiple heater elements **100** are turned on one by one to measure the voltage V.sub.2 for each, but the configuration of the present disclosure is not limited to this specific exemplary arrangement. In other words, when the self-bias voltage V.sub.dc is expected to be identical for some of the plurality of segmented regions **80**, the processing procedures described above may be carried out by simultaneously turning on the multiple heater elements **100** corresponding to the segmented regions **80** and turning off all other heater elements **100**. In this case, the voltage V.sub.2 measured by the measurement unit **106** may be considered as the average value of the voltages V.sub.2 measured by executing the processing procedures with the heater elements **100** turned on one by one.
(78) Further, in one example, although the measurement unit **106** is provided with the RF filter **124**, the configuration of the present disclosure is not limited to this specific exemplary arrangement. Specifically, instead of the RF filter **124**, an alternative component that may be considered equivalent to the capacitive element in the equivalent circuit in the example of FIG. **9** may be used. In this case, the operation of step ST**10** may be performed by designating the capacitance of the component, when considered equivalent to the capacitive element, as C.sub.3.
(79) Further, the constituent components of the aforementioned embodiments may be combined in any various ways. Through such combinations, the inherent functions and effects of each constituent component in the combination may be obtained, along with other functions and effects that would be apparent to those skilled in the art on the basis of the description herein. Furthermore, the effects described herein are presented as illustrative examples and are not intended to be limiting. In other words, the technology disclosed in the present application is capable of producing additional effects, evident to those skilled in the art from the description herein, in addition to or instead of the aforementioned effects.
(80) The following configuration is also within the technical scope of the present disclosure.
(81) (1) A plasma processing apparatus including: a plasma processing chamber; a base disposed in the plasma processing chamber; an electrostatic chuck disposed on top of the base; a plurality of

electrode layers disposed in the same plane within the electrostatic chuck; a switch group including a plurality of first switches electrically connected to the plurality of electrode layers, respectively; a power supply and a measurement unit that are electrically connected to the switch group; a second switch configured to select either the power supply or the measurement unit as a connection destination of the switch group; and a controller, wherein the power supply includes a power source that supplies a power to the plurality of electrode layers, the measurement unit includes a resistor and a voltmeter that measures a voltage applied to the resistor, and the controller is configured to execute a control operation that includes switching the connection destination of the switch group to the measurement unit and then turning ON the plurality of first switches constituting the switch group one by one.

(82) (2) The plasma processing apparatus according to the above (1), in which the measurement unit includes a capacitor disposed between the power supply and the switch group.

(83) (3) The plasma processing apparatus according to the above (1) or (2), in which the electrode layer is a heater electrode layer.

(84) (4) The plasma processing apparatus according to the above (1) or (2), in which the electrostatic chuck includes a clamping electrode layer, and the plurality of electrode layers is disposed on top of the clamping electrode layer.

(85) (5) The plasma processing apparatus according to the above (1) or (2), in which the switch group is disposed inside the base.

(86) (6) The plasma processing apparatus according to the above (2), in which the capacitor constitutes an RF filter.

(87) (7) The plasma processing apparatus according to the above (1) or (2), in which the controller is configured to execute a control operation that includes switching the connection destination of the switch group to the power supply and turning on all of the plurality of switches constituting the switch group, followed by switching the connection destination of the switch group to the measurement unit and then turning on the plurality of first switches one by one.

(88) (8) A plasma processing method including: providing a plasma processing apparatus including: a plasma processing chamber; a base disposed in the plasma processing chamber; an electrostatic chuck disposed on top of the base; a plurality of electrode layers disposed in the same plane within the electrostatic chuck; a switch group including a plurality of first switches electrically connected to the plurality of electrode layers, respectively; a power supply and a measurement unit that are electrically connected to the switch group, the power supply including a power source that supplies a power to the plurality of electrode layers, and the measurement unit including a resistor and a voltmeter that measures a voltage applied to the resistor; a second switch configured to select either the power supply or the measurement unit as a connection destination of the switch group; and a controller, switching the connection destination of the switch group to the measurement unit and then turning ON the plurality of first switches constituting the switch group one by one; and measuring the voltage using the measurement unit upon turning ON one of the plurality of first switches constituting the switch group.

(89) (9) The plasma processing method according to the above (8), further including: switching the connection destination of the switch group to the power supply and turning ON all of the plurality of first switches constituting the switch group, in which the switching the connection destination of the switch group to the power supply is executed, followed by the switching the connection destination of the switch group to the measurement unit and the measuring.

(90) (10) The plasma processing method according to the above (8) or (9), further including: calculating a self-bias voltage for a region in a substrate support corresponding to one of the plurality of first switches based on the voltage measured in the measuring.

(91) According to the present disclosure, it is possible to measure the in-plane distribution of the self-bias voltage of a substrate support.

(92) From the foregoing, it will be appreciated that various embodiments of the present disclosure

have been described herein for purposes of illustration, and that various modifications may be made without departing from the scope and spirit of the present disclosure. Accordingly, the various embodiments disclosed herein are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

Claims

1. A plasma processing apparatus comprising: a plasma processing chamber; a base disposed in the plasma processing chamber; an electrostatic chuck disposed on top of the base; a plurality of electrode layers disposed in a same plane within the electrostatic chuck; a switch group including a plurality of first switches electrically connected to the plurality of electrode layers, respectively; a power supply and a gauge that are electrically connected to the switch group, a second switch configured to select either the power supply or the gauge as a connection destination of the switch group; and a controller, wherein the power supply includes a power source that supplies a power to the plurality of electrode layers, the gauge includes a resistor and a voltmeter that measures a voltage applied to the resistor, and the controller is configured to execute a control operation that includes switching the connection destination of the switch group to the gauge and then turning ON the plurality of first switches constituting the switch group one by one.
2. The plasma processing apparatus according to claim 1, wherein the gauge includes a capacitor disposed between the power supply and the switch group.
3. The plasma processing apparatus according to claim 1, wherein the electrode a layers are heater electrode layers.
4. The plasma processing apparatus according to claim 1, wherein the electrostatic chuck further includes a clamping electrode layer, and the electrode layers are disposed on top of the clamping electrode layer.
5. The plasma processing apparatus according to claim 1, wherein the switch group is disposed inside the base.
6. The plasma processing apparatus according to claim 2, wherein the capacitor constitutes an RF filter.
7. The plasma processing apparatus according to claim 1, wherein the controller is configured to execute a control operation that includes switching the connection destination of the switch group to the power supply and turning ON all of the plurality of first switches constituting the switch group, followed by switching the connection destination of the switch group to the gauge and then turning ON the plurality of first switches one by one.
8. A plasma processing method comprising: providing a plasma processing apparatus including: a plasma processing chamber; a base disposed in the plasma processing chamber; an electrostatic chuck disposed on top of the base; a plurality of electrode layers disposed in a same plane within the electrostatic chuck; a switch group including a plurality of first switches electrically connected to the plurality of electrode layers, respectively; a power supply and a gauge that are electrically connected to the switch group, the power supply including a power source that supplies a power to the plurality of electrode layers, and the gauge including a resistor and a voltmeter that measures a voltage applied to the resistor; a second switch configured to select either the power supply or the gauge as a connection destination of the switch group; and a controller; switching the connection destination of the switch group to the gauge and then turning ON the plurality of first switches constituting the switch group one by one; and measuring the voltage using the gauge upon turning ON one of the plurality of first switches constituting the switch group.
9. The plasma processing method according to claim 8, further comprising: switching the connection destination of the switch group to the power supply and turning ON all of the plurality of first switches constituting the switch group, wherein the switching the connection destination of the switch group to the power supply is executed, followed by the switching the connection

destination of the switch group to the gauge and the measuring.

10. The plasma processing method according to claim 8, further comprising: calculating a self-bias voltage for a region in a substrate support corresponding to one of the plurality of first switches, based on the voltage measured in the measuring.