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Plasma processing apparatus and substrate processing method

Abstract

A plasma processing apparatus comprises a chamber, a substrate support, a plasma generator, a bias power supply and a chuck power supply. The substrate support includes a base and a dielectric part. The base includes a base member and an electrode. The base member is made of a dielectric or an insulator. The electrode is formed on an upper surface of the base member. The electrode forms an upper surface of the base. The dielectric part provides a supporting surface on which a substrate is placed. The dielectric part extends from the upper surface of the base to the supporting surface and is made of only a dielectric. The bias power supply and the chuck power supply are electrically connected to the electrode of the base.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a bypass continuation application of International Application No. PCT/JP2022/016485 having an international filing date of Mar. 31, 2022 and designating the United States, the International Application being based upon and claiming the benefit of priority from Japanese Patent Application No. 2021-073411, filed on Apr. 23, 2021, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD
(1) Exemplary embodiments of the present disclosure relate to a plasma processing apparatus and a substrate processing method.
BACKGROUND
(2) A plasma processing apparatus is used for plasma processing of a substrate. The plasma processing apparatus includes a chamber and a substrate support. The substrate support includes a base and an electrostatic chuck. The base constitutes a lower electrode. A bias power supply is connected to the base. The electrostatic chuck is disposed on the base. The electrostatic chuck includes an insulating layer and an electrode embedded in the insulating layer. A DC power supply is connected to the electrode of the electrostatic chuck. Japanese Laid-open Patent Publication No. 2019-169635 and Japanese Laid-open Patent Publication No. 2020-205444 disclose the above-described plasma processing apparatus.
SUMMARY
(3) The present disclosure provides a technique for efficiently supplying bias energy from a bias power supply to a substrate.
(4) In one exemplary embodiment of the present disclosure, a plasma processing apparatus is provided. The plasma processing apparatus comprises a chamber, a substrate support, a plasma generator, a bias power supply and a chuck power supply. The substrate support is disposed in the chamber. The plasma generator is configured to generate plasma in the chamber. The bias power supply is configured to generate bias energy for attracting ions from the plasma to a substrate. The chuck power supply is configured to generate a voltage applied to the substrate support to hold the substrate using an electrostatic attractive force. The bias energy is a radio frequency power or a periodically generated voltage pulse. The substrate support includes a base and a dielectric part. The base includes a base member and an electrode. The base member is made of a dielectric or an insulator. The electrode is formed on an upper surface of the base member. The electrode forms an upper surface of the base. The dielectric part provides a supporting surface on which the substrate is placed. The dielectric part extends from the upper surface of the base to the supporting surface and is made of only a dielectric. The bias power supply and the chuck power supply are electrically connected to the electrode of the base.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** schematically shows a plasma processing apparatus according to one exemplary embodiment.

(2) FIG. **2** schematically shows a plasma processing apparatus according to one exemplary embodiment.

(3) FIG. **3** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to one exemplary embodiment.

(4) FIG. **4** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to another exemplary embodiment.

(5) FIG. **5** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to still another exemplary embodiment.

(6) FIG. **6** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment.

(7) FIG. **7** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment.

(8) FIG. **8** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment.

(9) FIG. **9** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment.

(10) FIG. **10** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment.

(11) FIG. **11** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment.

(12) FIG. **12** is a flowchart of a substrate processing method according to one exemplary embodiment.

DETAILED DESCRIPTION

(13) Hereinafter, various exemplary embodiments will be described.

(14) In one exemplary embodiment of the present disclosure, a plasma processing apparatus is provided. The plasma processing apparatus comprises a chamber, a substrate support, a plasma generator, a bias power supply and a chuck power supply. The substrate support is disposed in the chamber. The plasma generator is configured to generate plasma in the chamber. The bias power supply is configured to generate bias energy for attracting ions from the plasma to a substrate. The chuck power supply is configured to generate a voltage applied to the substrate support to hold the substrate using an electrostatic attractive force. The bias energy is a radio frequency power or a periodically generated voltage pulse. The substrate support includes a base and a dielectric part. The base includes a base member and an electrode. The base member is made of a dielectric or an insulator. The electrode is formed on an upper surface of the base member. The electrode forms an upper surface of the base. The dielectric part provides a supporting surface on which the substrate is placed. The dielectric part extends from the upper surface of the base to the supporting surface and is made of only a dielectric. The bias power supply and the chuck power supply are electrically connected to the electrode of the base.

(15) In the above embodiment, the electrode is not disposed in the dielectric part, so that the thickness of the dielectric part can be reduced. Therefore, the impedance between the electrode of the base and the substrate is reduced. Accordingly, the bias energy is efficiently supplied to the substrate.

(16) In one exemplary embodiment of the present disclosure, the bias power supply may be electrically connected to the electrode via a capacitor. The bias power is separated from the chuck

power supply in a DC manner.
(17) In one exemplary embodiment of the present disclosure, the bias power supply and the chuck power supply may be electrically connected to the electrode via a wiring extending between the upper surface and a bottom surface of the base member.
(18) In one exemplary embodiment of the present disclosure, the plasma generator may include a radio frequency power supply electrically connected to the electrode of the base.
(19) In one exemplary embodiment of the present disclosure, the supporting surface may include a first region on which the substrate is placed and a second region on which an edge ring is placed. In this embodiment, the electrode is a first electrode disposed below the first region. The base may further include a second electrode. The second electrode is disposed below the second region, forms the upper surface of the base, and is separated from the first electrode. The bias power supply or another bias power supply and another chuck power supply are electrically connected to the second electrode.
(20) In one exemplary embodiment of the present disclosure, the second electrode may include two electrodes constituting a bipolar electrode. Said another chuck power supply may include two power supplies respectively connected to the two electrodes.
(21) In one exemplary embodiment of the present disclosure, the bias power supply or said another bias power supply may be electrically connected to the second electrode via a capacitor. The bias power supply or said another bias power supply is separated from said another chuck power supply in a DC manner.
(22) In one exemplary embodiment of the present disclosure, the bias power supply or said another bias power supply and said another chuck power supply may be electrically connected to the second electrode via a wiring extending between the upper surface and a bottom surface of the base member.
(23) In one exemplary embodiment of the present disclosure, a plasma processing apparatus is provided. The plasma processing apparatus includes a chamber, a substrate support, a plasma generator, a bias power supply and a chuck power supply. The substrate support is disposed in the chamber. The plasma generator is configured to generate plasma in the chamber. The bias power supply is configured to generate bias energy for attracting ions from the plasma to a substrate. The chuck power supply is configured to generate a voltage applied to the substrate support to hold the substrate using an electrostatic attractive force. The bias energy is a radio frequency power or a periodically generated voltage pulse. The substrate support includes a base and a dielectric part. The dielectric part provides a supporting surface on which a substrate is placed, extends from an upper surface of the base to the supporting surface, and is made of only a dielectric. The supporting surface includes a first region on which the substrate is placed and a second region on which an edge ring is placed. The base includes a first portion and a second portion. The first portion is made of a conductive material and disposed below the first region. The second portion is made of a conductive material, disposed below the second region, and separated from the first portion. The bias power supply and the chuck power supply are electrically connected to the first portion. The bias power supply or another bias power supply and another chuck power supply are electrically connected to the second portion.
(24) In the above embodiment, the electrode is not disposed in the dielectric part, so that the thickness of the dielectric part can be reduced. Therefore, the impedance between the first portion of the base and the substrate and the impedance between the second portion of the base and the edge ring are reduced. Accordingly, the bias energy is efficiently delivered to the substrate and the edge ring.
(25) In one exemplary embodiment of the present disclosure, the second portion may include two portions constituting a bipolar electrode. Said another chuck power supply may include two power supplies respectively connected to the two portions.
(26) In one exemplary embodiment of the present disclosure, the bias power supply may be

electrically connected to the first portion via a capacitor. The bias power supply is separated from the chuck power supply in a DC manner. The bias power supply or said another bias power supply may be electrically connected to the second portion via a capacitor. The bias power supply or said another bias power supply is separated from the separate chuck power supply in a DC manner.
(27) In one exemplary embodiment of the present disclosure, the plasma generator may include a radio frequency power supply electrically connected to the first portion of the base.
(28) In another exemplary embodiment of the present disclosure, a substrate processing method using the plasma processing apparatus according to one of the exemplary embodiments is provided. The substrate processing method comprises placing a substrate on the dielectric part of the substrate support. The substrate processing method comprises generating plasma in the chamber using the plasma generator. The substrate processing method comprises holding the substrate on the substrate support by supplying a voltage from the chuck power supply. The substrate processing method comprises attracting ions from the plasma to the substrate by supplying the bias energy from the bias power supply.
(29) Hereinafter, various exemplary embodiments will be described in detail with reference to the accompanying drawings. Further, like reference numerals will be used for like or corresponding parts throughout the drawings.
(30) FIGS. **1** and **2** schematically show a plasma processing apparatus according to one exemplary embodiment.
(31) In one embodiment, a plasma processing system includes a plasma processing apparatus **1** and a controller **2**. 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. Further, the plasma processing chamber **10** includes at least one gas inlet for supplying at least one processing gas to the plasma processing space, and at least one gas outlet for exhausting a gas from the plasma processing space. The gas inlet is connected to a gas supply part **20** to be described later, and the gas outlet is connected to an exhaust system **40** to be described later. The substrate support **11** is disposed in the plasma processing space, and has a substrate supporting surface for supporting the substrate.
(32) The plasma generator **12** is configured to generate plasma from at least one processing gas supplied into the plasma processing space. The plasma generated in the plasma processing space includes capacitively coupled plasma (CCP), inductively coupled plasma (ICP), electron-cyclotron-resonance (ECR) plasma, and helicon wave excited (HWP) plasma, surface wave plasma (SWP), or the like. Further, various types of plasma generators including an alternating current (AC) plasma generator and a direct current (DC) plasma generator may be used. In one embodiment, an AC signal (AC power) used in the AC plasma generator has a frequency within a range of 100 kHz to 10 GHz. Therefore, the AC signal includes a radio frequency (RF) signal and a microwave signal. In one embodiment, the RF signal has a frequency within a range of 200 kHz to 150 MHz.
(33) The controller **2** processes computer-executable instructions that cause the plasma processing apparatus **1** to perform various steps described in the present disclosure. The controller **2** may be configured to control individual components of the plasma processing apparatus **1** to perform various steps described herein. In one embodiment, the controller **2** may be partially or entirely included in the plasma processing apparatus **1**. The controller **2** may include, for example, a computer **2***a*. The computer **2***a* may include, for example, a central processing unit (CPU) **2***a***1**, a storage device **2***a***2**, and a communication interface **2***a***3**. The central processing unit **2***a***1** may be configured to perform various control operations based on programs stored in the storage device **2***a***2**. The storage device **2***a***2** 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 thereof. The communication interface **2***a***3** may communicate with the plasma processing apparatus **1** through a communication line such as a local area network (LAN).
(34) Hereinafter, a configuration example of a capacitively coupled plasma processing apparatus as

an example of the plasma processing apparatus **1** will be described. The capacitively coupled plasma processing apparatus **1** includes a plasma processing chamber **10**, a gas supply part **20**, a plurality of power supplies, and an exhaust system **40**. The plasma processing apparatus **1** further includes a substrate support **11** and a gas introducing part. The gas introducing part is configured to introduce at least one processing gas into the plasma processing chamber **10**. The gas introducing part includes a shower head **13**. The substrate support **11** is disposed in the plasma processing chamber **10**. The shower head **13** is disposed above the substrate support **11**. In one embodiment, the shower head **13** forms at least a part of the ceiling of the plasma processing chamber **10**. The plasma processing chamber **10** has a plasma processing space **10***s* defined by the shower head **13**, a sidewall **10***a* of the plasma processing chamber **10**, and the substrate support **11**. The sidewall **10***a* is grounded. The shower head **13** and the substrate support **11** are electrically insulated from the housing of the plasma processing chamber **10**.
(35) The substrate support **11** is configured to support the substrate W placed thereon. The substrate support **11** is configured to further support an edge ring ER placed thereon. The edge ring ER is an annular member, and is made of a material such as silicon or silicon carbide. The substrate W is placed on the substrate support **11** and is disposed in the region surrounded by the edge ring ER. The substrate support **11** may include a temperature control module configured to adjust at least one of the edge ring ER and the substrate W to a target temperature. The temperature control module may include a heater, heat transfer medium, a channel, or combinations thereof. A heat transfer fluid, such as brine or a gas, flows through the channel. Further, the substrate support **11** may include a heat transfer gas supply part configured to supply a heat transfer gas to a gap between the backside of the substrate W and a substrate supporting surface **111***a*.
(36) The shower head **13** is configured to introduce at least one processing gas from the gas supply part **20** into the plasma processing space **10***s*. The shower head **13** has at least one gas supply port **13***a*, at least one gas diffusion space **13***b*, and a plurality of gas inlet ports **13***c*. The processing gas supplied to the gas supply port **13***a* passes through the gas diffusion space **13***b* and is introduced into the plasma processing space **10***s* from the gas inlet ports **13***c*. The shower head **13** also includes a conductive member. The conductive member of the shower head **13** functions as an upper electrode. The gas introducing part may include, in addition to the shower head **13**, one or more side gas injectors (SGI) attached to one or more openings formed in the sidewall **10***a*.
(37) The gas supply part **20** may include at least one gas source **21** and at least one flow rate controller **22**. In one embodiment, the gas supply part **20** is configured to supply at least one processing gas from the corresponding gas source **21** to the shower head **13** through the corresponding flow rate controller **22**. The flow rate controllers **22** may include, for example, a mass flow controller or a pressure-controlled flow rate controller. Further, the gas supply part **20** may include at least one flow modulation device for modulating the flow rate of at least one processing gas or causing it to pulsate.
(38) The power supplies include one or more radio frequency power supplies constituting the plasma generator, one or more bias power supplies for generating bias energy for attracting ions to the substrate, and one or more chuck power supplies for maintaining the substrate W and the edge ring ER using an electrostatic attractive force. These power supplies will be described later.
(39) The exhaust system **40** may be connected to a gas exhaust port **10***e* disposed at the bottom portion of the plasma processing chamber **10**, for example. The exhaust system **40** may include a pressure control valve and a vacuum pump. The pressure in the plasma processing space **10***s* is adjusted by the pressure control valve. The vacuum pump may include a turbo molecular pump, a dry pump, or a combination thereof.
(40) Hereinafter, FIG. **3** will be referred to. FIG. **3** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to one exemplary embodiment. The substrate support section **11**A shown in FIG. **3** may be employed as the substrate support section **11** of the plasma processing apparatus **1**.

(41) A substrate support **11**A includes a base **16** and a dielectric part **18**. The base **16** includes a base member **16***b* and one or more electrodes. The base member **16***b* is made of a dielectric or an insulator. The base member **16***b* has a substantially disc shape. The base member **16***b* is made of ceramic, such as aluminum nitride or aluminum oxide.
(42) One or more electrodes of the base **16** are formed on the upper surface of the base member **16***b*. One or more electrodes of the base **16** constitute an upper surface **16***u* of the base **16**. One or more electrodes of base **16** may be conductive films. In one embodiment, the base **16** may include, as one or more electrodes, a first electrode **161** and a second electrode **162**. The first electrode **161** includes the center of the upper surface **16***u*, and has a substantially circular shape. The second electrode **162** is separated from the first electrode **161**. The second electrode **162** may extend in a circumferential direction to surround the first electrode **161**. In other words, the second electrode **162** may have an annular shape.
(43) In one embodiment, the second electrode **162** may include two electrodes **162***a* and **162***b* constituting a bipolar electrode. The two electrodes **162***a* and **162***b* are separated from each other. Each of the two electrodes **162***a* and **162***b* may have an annular shape. One of the two electrodes **162***a* and **162***b* may extend in the circumferentially direction at a radially outer side of the other electrode. Alternatively, each of the two electrodes **162***a* and **162***b* may include a plurality of electrodes that are separated from each other and arranged in the circumferential direction.
(44) In one embodiment, the base **16** may include an electrode **163**. The electrode **163** may be a conductive film formed on the bottom surface of the base member **16***b*. In one embodiment, the base **16** may include a plurality of wirings **165**, **166***a*, and **166***b*. The wirings **165**, **166***a*, and **166***b* extend between the upper surface and the bottom surface of the base member **16***b*. One or more wirings **165** connect the first electrode **161** and the electrode **163**. One or more wirings **166***a* are connected to the electrode **162***a*. One or more wirings **166***b* are connected to the electrode **162***b*. Each of the wirings **165**, **166***a*, and **166***b* may be a via hole formed in the base member **16***b*. Alternatively, each of the wirings **165**, **166***a*, and **166***b* may be a conductor line formed along the surface of the base member **16***b*. The electrode **163** may be a planar electrode, or may be a wiring that connects the power supply points for the first electrode **161**, the electrode **162***a*, and the electrode **162***b* to the wiring **165**, **166***a*, and **166***b*, respectively.
(45) The dielectric part **18** provides a supporting surface **18***s* on which the substrate W is placed. The dielectric part **18** extends from the upper surface **16***u* of the base **16** to the supporting surface **18***s*, and is made of only a dielectric. The dielectric part **18** is made of ceramic such as aluminum nitride or aluminum oxide.
(46) In one embodiment, the supporting surface **18***s* of the dielectric part **18** may include a first region **181** and a second region **182**. The first region **181** includes the center of the supporting surface **18***s*, and has a substantially circular shape. The substrate W is placed on the first region **181**. The first region **181** extends above the first electrode **161** of the base **16**. In other words, the first electrode **161** is disposed below the first region **181**.
(47) The second region **182** extends in the circumferential direction at a radially outer side of the first region **181**. In other words, the second region **182** has an annular shape. The edge ring ER is placed on the second region **182**. The second region **182** extends above the second electrode **162** of the base **16**. In other words, the second electrode **162** (the electrodes **162***a* and **162***b*) is disposed below the second region **182**.
(48) In one embodiment, the substrate support **11** may further include an insulator part **11***i*. The insulator part **11***i* covers the end surface (the outer circumferential surface) of the first electrode **161** and the inner end surface (the inner circumferential surface) of the second electrode **162** to hide them from plasma. In one embodiment, the dielectric part **18** may be separated into a portion providing the first region **181** and a portion providing the second region **182**. The insulator part **11***i* may be interposed between the outer circumferential surface of the portion providing the first region **181** and the inner circumferential surface of the portion providing the second region **182**.

(49) The power supplies of the plasma processing apparatus **1** may include chuck power supplies **31**, **32**, and **33**. Each of the chuck power supplies **31**, **32**, and **33** is a DC power supply or a variable DC power supply. The chuck power supply **31** is connected to the first electrode **161** via a switch **31***s*, an electrode **163**, and one or more wirings **165**. When a DC voltage from the chuck power supply **31** is applied to the first electrode **161**, the substrate W is attracted to the first region **181** by the electrostatic attractive force and is held on the substrate support **11**A.
(50) The chuck power supply **32** is connected to the electrode **162***a* via a switch **32***s* and one or more wirings **166***a*. The chuck power supply **33** is connected to the electrode **162***b* via a switch **33***s* and one or more wirings **166***b*. When a DC voltage from the chuck power supply **32** is applied to the electrode **162***a* and a DC voltage from the chuck power supply **33** is applied to the electrode **162***b*, the edge ring ER is attracted to the second region **182** by the electrostatic attractive force and is held on the substrate support **11**A.
(51) The power supplies of the plasma processing apparatus **1** include one or more radio frequency power supplies and one or more bias power supplies. In the example shown in FIG. **3**, the power supplies include a radio frequency power supply **51**, a radio frequency power supply **52**, a bias power supply **53**, and a bias power supply **54**.
(52) The radio frequency power supply **51** and the radio frequency power supply **52** constitute a plasma generator of one embodiment. Each of the radio frequency power supply **51** and the radio frequency power supply **52** generates a radio frequency power having a frequency suitable for generating plasma from a gas in the chamber **10**. The radio frequency power generated by each of the radio frequency power supplies **51** and **52** has a frequency within a range of 13 MHz to 150 MHz, for example.
(53) The radio frequency power supply **51** is connected to the first electrode **161** via a matching device **51***m*, an electrode **163**, and one or more wirings **165**. The matching device **51***m* includes a matching circuit for matching an impedance of a load of the radio frequency power supply **51** with an output impedance of the radio frequency power supply **51**.
(54) The radio frequency power supply **52** is connected to the electrode **162***a* via a matching device **52***m*, a capacitor **54***ca*, and one or more wirings **166***a*. Further, the radio frequency power supply **52** is connected to the electrode **162***b* via the matching device **52***m*, a capacitor **54***cb*, and one or more wirings **166***b*. The matching device **52***m* includes a matching circuit for matching the impedance of the load of the radio frequency power supply **52** with the output impedance of the radio frequency power supply **52**. The capacitor **54***ca* separates the radio frequency power supply **52** from the chuck power supply **32** in a DC manner. The capacitor **54***cb* separates the radio frequency power supply **52** from the chuck power supply **33** in a DC manner.
(55) The bias power supplies **53** and **54** generate bias energy for attracting ions to the substrate W and the edge ring ER. The bias energy may be a radio frequency bias power. The radio frequency bias power has a frequency within a range of 100 kHz to 13.56 MHz, for example. Alternatively, the bias energy may be periodically generated voltage pulses. The voltage pulse has positive polarity or negative polarity. The voltage pulse may have any waveform. The voltage pulse may be a negative DC voltage pulse. The voltage pulse is generated periodically with a repetition frequency within a range of 100 kHz to 13.56 MHz.
(56) The bias power supply **53** is connected to the first electrode **161** via a matching device **53***m*, a capacitor **53***c*, an electrode **163**, and one or more wirings **165**. The matching device **53***m* includes a matching circuit for matching the impedance of the load of the bias power supply **53** with the output impedance of the bias power supply **53**. The capacitor **53***c* is provided to separate the bias power supply **53** from the chuck power supply **31** in a DC manner.
(57) The bias power supply **54** is connected to the electrode **162***a* via a matching device **54***m*, a capacitor **54***ca*, and one or more wirings **166***a*. Further, the bias power supply **54** is connected to the electrode **162***b* via a matching device **54***m*, a capacitor **54***cb*, and one or more wirings **166***b*. The matching device **54***m* includes a matching circuit for matching the impedance of the load of the

bias power supply **54** with the output impedance of the bias power supply **54**. The capacitor **54***ca* is provided to separate the bias power supply **54** from the chuck power supply **32** in a DC manner. The capacitor **54***cb* is provided to separate the bias power supply **54** from the chuck power supply **33** in a DC manner.

(58) In the plasma processing apparatus **1**, no electrode is disposed in the dielectric part **18**, so that the thickness of the dielectric part **18** can be reduced. Therefore, the impedance between the first electrode **161** of the base **16** and the substrate W is reduced. Further, the impedance between each of the electrodes **162***a* and **162***b* of the base **16** and the edge ring ER is reduced. Accordingly, the bias energy is efficiently supplied to the substrate W. Further, the bias energy is efficiently supplied to the edge ring ER. Moreover, the radio frequency power is efficiently coupled to the plasma via the substrate W and the edge ring ER. Thus, it is possible to reduce the bias energy. Further, it is possible to reduce the radio frequency power. Hence, heat generation at the electrodes of the substrate support **11**A, the contact points, and the like is suppressed.

(59) Since the base member **16***b* of the base **16** is made of a dielectric or an insulator, the difference between the thermal expansion coefficient of the base **16** and the thermal expansion coefficient of the dielectric part **18** is small. Therefore, the damage to the substrate support **11**A due to the difference between the thermal expansion coefficient of the base **16** and the thermal expansion coefficient of the dielectric part **18** is suppressed.

(60) In one embodiment, the dielectric part **18** may satisfy the following Eq. (1).

$$0.5\times C\text{.sub.W0}/S\text{.sub.W}<C\text{.sub.FO}/S\text{.sub.F}<1.5\times C\text{.sub.W0}/S\text{.sub.W} \qquad \text{Eq. (1)}$$

(61) In Eq. (1), C.sub.W0 indicates the capacitance between the base **16** and the substrate W. S.sub.W indicates the area of one main surface (for example, the bottom surface or the surface in contact with plasma) of the substrate W. C.sub.FO indicates the capacitance between the base **16** and the edge ring ER. Se indicates the area of one main surface (for example, the bottom surface or the surface in contact with plasma) of the edge ring. By satisfying Eq. (1), the difference between the power density of the radio frequency power coupled to the plasma via the substrate W and the power density of the radio frequency power coupled to the plasma via the edge ring ER is reduced. Therefore, the variation in the plasma density in the chamber is suppressed.

(62) In one embodiment, the substrate support **11**A may be configured such that the capacitance between the substrate W and the edge ring ER becomes 10 nF or less or 3 nF or less. Accordingly, the electrical coupling between the substrate W and the edge ring ER is suppressed.

(63) Hereinafter, FIG. **4** will be referred to. FIG. **4** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to another exemplary embodiment. A substrate support **11**B shown in FIG. **4** may be employed as the substrate support **11** of the plasma processing apparatus **1**. The substrate support **11**B further includes one or more wirings **165***a* and one or more wirings **165***b*. One or more wirings **165***a* and one or more wirings **165***b* extend between the upper surface and the bottom surfaces of the base member **16***b*. One or more wirings **165***a* connect the electrode **163** and the electrode **162***a*. One or more wiring **165***b* connects the electrode **163** and the electrode **162***b*.

(64) Each of one or more wirings **165***a* and one or more wirings **165***b* may be a via hole formed in the base member **16***b*. Alternatively, each of one or more wirings **165***a* and one or more wirings **165***b* may be a conductor line formed along the surface of the base member **16***b*.

(65) In the example shown in FIG. **4**, the plasma processing apparatus **1** does not include the radio frequency power supply **52** and the matching device **52***m*. In the example shown in FIG. **4**, the radio frequency power supply **51** is connected to the electrode **162***a* via the matching device **51***m*, the electrode **163**, and one or more wirings **165***a*. Further, the radio frequency power supply **51** is connected to the electrode **162***b* via the matching device **51***m*, the electrode **163**, and one or more wirings **165***b*. In the example shown in FIG. **4**, the radio frequency power from the single radio frequency power supply **51** is distributed to the first electrode **161** and the second electrode **162**. The other configurations in the example shown in FIG. **4** are the same as those of the example

shown in FIG. **3**.
(66) Hereinafter, FIG. **5** will be referred to. FIG. **5** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to still another exemplary embodiment. As shown in FIG. **5**, the plasma processing apparatus **1** may not include the radio frequency power supply **52**, the matching device **52***m*, the bias power supply **54**, and the matching device **54***m*.
(67) As shown in FIG. **5**, the radio frequency power supply **51** is connected to the electrode **162***a* via the matching device **51***m*, an impedance circuit **56**, a capacitor **53***ca*, and the wiring **166***a*. Further, the radio frequency power supply **51** is connected to the electrode **162***b* via the matching device **51***m*, the impedance circuit **56**, a capacitor **53***cb*, and the wiring **166***b*. The bias power supply **53** is connected to the electrode **162***a* via the matching device **53***m*, the impedance circuit **56**, the capacitor **53***ca*, and the wiring **166***a*. Further, the bias power supply **53** is connected to the electrode **162***b* via the matching device **53***m*, the impedance circuit **56**, the capacitor **53***cb*, and the wiring **166***b*. The capacitor **53***ca* is provided to separate the radio frequency power supply **51** and the bias power supply **53** from the chuck power supply **32** in a DC manner. The capacitor **53***cb* is provided to separate the radio frequency power supply **51** and the bias power supply **53** from the chuck power supply **33** in a DC manner.
(68) The impedance circuit **56** has a variable impedance. The impedance circuit includes a variable impedance element, such as a variable capacitor. In the plasma processing apparatus **1** of the example shown in FIG. **5**, the radio frequency power from the single radio frequency power supply **51** is distributed to the first electrode **161** and the second electrode **162**. Further, in the plasma processing apparatus **1** of the example shown in FIG. **5**, the bias energy from the single bias power supply **53** is distributed to the first electrode **161** and the second electrode **162**. A distribution ratio of each of the radio frequency power and the bias energy is set by adjusting the variable impedance of the impedance circuit **56**. The other configurations in the example shown in FIG. **5** are the same as those in the example shown in FIG. **3**.
(69) Hereinafter, FIG. **6** will be referred to. FIG. **6** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment. A substrate support **11**D shown in FIG. **6** may be employed as the substrate support **11** of the plasma processing apparatus **1**. The substrate support **11**D has a base **16**D instead of the base **16**. The base **16**D includes a first portion **161**D and a second portion **162**D.
(70) Each of the first portion **161**D and the second portion **162**D are made of a conductive material. Each of the first portion **161**D and the second portion **162**D is made of a metal such as aluminum or a metal-ceramic composite.
(71) The first portion **161**D is disposed below the first region **181**. The first portion **161**D includes the center of the base **16**D and has a substantially disc shape. The second portion **162**D is disposed below the second region **182**. The second portion **162**D extends in the circumferential direction at a radially outer side of the first portion **161**D. The second portion **162**D may have a substantially annular shape in plan view. The second portion **162**D is separated from the first portion **161**D. The gap between the first portion **161**D and the second portion **162**D may be filled with an insulator material (the insulator part **11***i*) or a dielectric material.
(72) In one embodiment, the second portion **162**D may include portions **162***e* and **162***f*. The portions **162***e* and **162***f* constitute a bipolar electrode. Each of portions **162***e* and **162***f* extends in the circumferential direction at the radially outer side of the first portion **161**D. Each of the portions **162***e* and **162***f* may have a substantially annular shape in plan view. The portion **162***f* may extend in the circumferential direction at the radially outer side of the portion **162***e*. The portions **162***e* and **162***f* are separated from each other. The gap between the portions **162***e* and **162***f* may be filled with an insulator material or a dielectric material.
(73) The chuck power supply **31** is connected to the first portion **161**D via the switch **31***s*. When a DC voltage from the chuck power supply **31** is applied to the first portion **161**D, the substrate W is attracted to the first region **181** by an electrostatic attractive force and held on the substrate support

11D.

(74) The chuck power supply **32** is connected to the portion **162***e* via the switch **32***s*. The chuck power supply **33** is connected to the portion **162***f* via the switch **33***s*. When a DC voltage from the chuck power supply **32** is applied to the portion **162***e* and a DC voltage from the chuck power supply **33** is applied to the portion **162***f*, the edge ring ER is attracted to the second region **182** by an electrostatic attractive force and held on the substrate support **11**D.

(75) The radio frequency power supply **51** is connected to the first portion **161**D via the matching device **51***m*. The radio frequency power supply **52** is connected to the portion **162***e* via the matching device **52***m* and the capacitor **54***ca*. Further, the radio frequency power supply **52** is connected to the portion **162***f* via the matching device **52***m* and the capacitor **54***cb*.

(76) The bias power supply **53** is connected to the first portion **161**D via the matching device **53***m* and the capacitor **53***c*. The bias power supply **54** is connected to the portion **162***e* via the matching device **54***m* and the capacitor **54***ca*. The bias power supply **54** is connected to the portion **162***f* via the matching device **54***m* and the capacitor **54***cb*.

(77) In the substrate support **11**D, no electrode is disposed in the dielectric part **18**, so that the thickness of the dielectric part **18** can be reduced. Therefore, the impedance between the first portion **161**D of the base **16**D and the substrate W and the impedance between the second portion **162**D of the base **16**D and the edge ring ER are reduced. Accordingly, the bias energy is efficiently supplied to the substrate W and the edge ring ER.

(78) In one embodiment, the dielectric part **18** may satisfy the following Eq. (2).

$$0.5\times C_{W0}/S_{W}<C_{FO}/S_{F}<1.5\times C_{W0}/S_{W} \qquad \text{Eq. (2)}$$

(79) In Eq. (2), C.sub.W0 indicates the capacitance between the base **16**D and the substrate W. S.sub.W indicates the area of one main surface (for example, the bottom surface or the surface in contact with plasma) of the substrate W. C.sub.FO indicates the capacitance between the base **16**D and the edge ring ER. S.sub.F indicates the area of one main surface (for example, the bottom surface or the surface in contact with plasma) of the edge ring ER. By satisfying Eq. (2), the difference between the power density of the radio frequency power coupled to the plasma via the substrate W and the power density of the radio frequency power coupled to the plasma via the edge ring ER is reduced. Therefore, the variation in the plasma density in the chamber is suppressed.

(80) In one embodiment, the substrate support **11**D may be configured such that the capacitance between the substrate W and the edge ring ER becomes 10 nF or less or 3 nF or less. Accordingly, the electrical coupling between the substrate W and the edge ring ER is suppressed.

(81) Hereinafter, FIG. **7** will be referred to. FIG. **7** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment. As shown in FIG. **7**, the plasma processing apparatus **1** may not include the radio frequency power supply **52**, the matching device **52***m*, the bias power supply **54**, and the matching device **54***m*.

(82) As shown in FIG. **7**, the radio frequency power supply **51** is connected to the portion **162***e* via the matching device **51***m*, the impedance circuit **56**, and the capacitor **53***ca*. Further, the radio frequency power supply **51** is connected to the portion **162***f* via the matching device **51***m*, the impedance circuit **56**, and the capacitor **53***cb*. The bias power supply **53** is connected to the portion **162***e* via the matching device **53***m*, impedance circuit **56**, and the capacitor **53***ca*. Further, the bias power supply **53** is connected to the portion **162***f* via the matching device **53***m*, the impedance circuit **56**, and the capacitor **53***cb*.

(83) In the example plasma processing apparatus **1** shown in FIG. **7**, the radio frequency power from the single radio frequency power supply **51** is distributed to the first portion **161**D and the second portion **162**D. Further, in the example plasma processing apparatus **1** shown in FIG. **7**, the bias energy from the single bias power supply **53** is distributed to the first portion **161**D and the second portion **162**D. A distribution ratio of each of the radio frequency power and the bias energy is set by adjusting the variable impedance of the impedance circuit **56**. The other configurations in

the example shown in FIG. **7** are the same as those in the example shown in FIG. **6**.

(84) Hereinafter, FIG. **8** will be referred to. FIG. **8** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment. In the substrate support **11**A and the substrate support **11**B described above, the second electrode **162** includes two electrodes. On the other hand, in the substrate support **11**E shown in FIG. **8**, the second electrode **162**E is configured as a single electrode. The wiring **166** extending from the bottom surface of the base member **16***b* while passing through the end surface is connected to the second electrode **162**E. Each of one or more wirings **165** may connect the electrode **163** and the first electrode **161** via a groove formed at the peripheral portion of the base member **16***b*.

(85) The chuck power supply **32** is connected to the second electrode **162**E via the switch **32***s* and the wiring **166**. Further, the radio frequency power supply **52** is connected to the second electrode **162**E via the matching device **52***m*, a capacitor **54***c*, and the wiring **166**. Further, the bias power supply **54** is connected to the second electrode **162**E via the matching device **54***m*, the capacitor **54***c*, and the wiring **166**. The radio frequency power from the radio frequency power supply **51** may be distributed to the first electrode **161** and the second electrode **162**E. Further, the bias energy from the bias power supply **53** may be distributed to the first electrode **161** and the second electrode **162**E.

(86) Hereafter, FIG. **9** will be referred to. FIG. **9** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment. In the substrate support **11**D described above, the second portion **162**D includes the two portions **162***e* and **162***f*. On the other hand, in the base **16**F of the substrate support **11**F shown in FIG. **9**, a second portion **162**F is formed as a single portion.

(87) The chuck power supply **32** is connected to the second portion **162**F via the switch **32***s*. Further, the radio frequency power supply **52** is connected to the second portion **162**F via the matching device **52***m* and the capacitor **54***c*. Further, the bias power supply **54** is connected to the second portion **162**F via the matching device **54***m* and the capacitor **54***c*. The radio frequency power from the radio frequency power supply **51** may be distributed to the first portion **161**D and the second portion **162**F. Further, the bias energy from the bias power supply **53** may be distributed to the first portion **161**D and the second portion **162**F.

(88) Hereinafter, FIG. **10** will be referred to. FIG. **10** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment. The example shown in FIG. **10** is a modification of the example shown in FIG. **3**. In the example shown in FIG. **10**, a channel **16***f* is formed in the base **16**. A heat medium (for example, a coolant) is supplied from a supply device to the channel **16***f*. The heat medium flows through the channel **16***f* and returns to the supply device. The channel **16***f* may be formed to have a wide cross-sectional area without decreasing the mechanical strength of the base **16**. The channel **16***f* may be formed in the base **16** in the above-described examples other than the example shown in FIG. **3**.

(89) Hereafter, FIG. **11** will be referred to. FIG. **11** shows a substrate support and a plurality of power supplies of a plasma processing apparatus according to further still another exemplary embodiment. The example shown in FIG. **11** is a modification of the example shown in FIG. **6**. In the example shown in FIG. **11**, the channel **16***f* is formed in the base **16**D. A heat medium (for example, a coolant) is supplied from a supply device to the channel **16***f*. The heat medium flows through the channel **16***f* and returns to the supply device. The channel **16***f* may be formed to have a wide cross-sectional area without decreasing the mechanical strength of the base **16**D. The channel **16***f* may be formed in the base **16**D in the above-mentioned examples other than the example shown in FIG. **6**. The channel **16***f* may be formed in the base **16**F in the example shown in FIG. **9**.

(90) Hereinafter, FIG. **12** will be referred to. FIG. **12** is a flowchart of a substrate processing method according to one exemplary embodiment. The substrate processing method shown in FIG.

12 (hereinafter, referred to as “method MT”) can be performed using the plasma processing apparatus **1** described above. In the method MT, the individual components of the plasma processing apparatus **1** can be controlled by the controller **2**. The method MT includes steps STa, STb, STc, and STd.
(91) In step STa, the substrate W is placed on the dielectric part **18** of the substrate support. Steps STb, STc, and STd are performed in a state where the substrate W is placed on the dielectric part **18**.
(92) In step STb, plasma is generated in the chamber **10** using the plasma generator. In step STb, the processing gas is supplied from the gas supply part **20** into the plasma processing chamber **10**. Further, in step STb, the exhaust system **40** reduces a pressure in the plasma processing chamber **10** to a specified pressure. Further, in step STb, the radio frequency power is supplied to generate plasma from the processing gas.
(93) In step STc, the substrate W is held by the substrate support by applying a voltage from the chuck power supply **31**. The edge ring ER may be held by the substrate support in step STc by applying a voltage from the chuck power supply **32** and the chuck power supply **33**. Alternatively, the edge ring ER may be held by the substrate support before step STb.
(94) Step STd is performed when the plasma is generated in step STb. In step STd, the bias energy is supplied to attract ions from the plasma to the substrate W.
(95) While various exemplary embodiments have been described above, the present disclosure is not limited to the above-described embodiments, and various additions, omissions, substitutions and changes may be made. Further, other embodiments can be implemented by combining elements in different embodiments.
(96) For example, the radio frequency power from the radio frequency power supply may be supplied to the upper electrode instead of the substrate support. Further, in another embodiment, the plasma processing apparatus may be a plasma processing apparatus other than a capacitively coupled plasma processing apparatus. Such a plasma processing apparatus may be an inductively coupled plasma processing apparatus, an electron cyclotron resonance (ECR) plasma processing apparatus, or a plasma processing apparatus for generating plasma using surface waves such as microwaves.
(97) From the above description, it will be appreciated that various embodiments of the present disclosure have been described herein for purposes of illustration, and that various changes may be made without departing from the scope and spirit of the present disclosure. Therefore, the various embodiments disclosed herein are not intended to be limiting, with a true scope and spirit being indicated by the following claims.

Claims

1. A plasma processing apparatus comprising: a chamber; a substrate support disposed in the chamber; a plasma generator configured to generate plasma in the chamber; a bias power supply configured to generate bias energy for attracting ions from the plasma to a substrate; and a chuck power supply configured to generate a voltage applied to the substrate support to hold the substrate using an electrostatic attractive force, wherein the bias energy is a radio frequency power or a periodically generated voltage pulse, the substrate support includes: a base including a base member made of a dielectric or an insulator and an electrode formed on an upper surface of the base member, the electrode forming an upper surface of the base; and a dielectric part that provides a supporting surface on which the substrate is placed, extends from the upper surface of the base to the supporting surface, and is made of only a dielectric, and the bias power supply and the chuck power supply are electrically connected to the electrode of the base.
2. The plasma processing apparatus of claim 1, wherein the bias power supply is electrically connected to the electrode via a capacitor, and is separated from the chuck power supply in a DC

manner.

3. The plasma processing apparatus of claim 1, wherein the bias power supply and the chuck power supply are electrically connected to the electrode via a wiring extending between the upper surface and a bottom surface of the base member.

4. The plasma processing apparatus of claim 1, wherein the plasma generator includes a radio frequency power supply electrically connected to the electrode of the base.

5. The plasma processing apparatus of claim 1, wherein the supporting surface includes a first region on which the substrate is placed and a second region on which an edge ring is placed, the electrode is a first electrode disposed below the first region, the base further includes a second electrode, the second electrode is disposed below the second region, forms the upper surface of the base, and is separated from the first electrode, and the bias power supply or another bias power supply and another chuck power supply are electrically connected to the second electrode.

6. The plasma processing apparatus of claim 5, wherein the second electrode includes two electrodes constituting a bipolar electrode, and said another chuck power supply includes two power supplies respectively connected to the two electrodes.

7. The plasma processing apparatus of claim 5, wherein the bias power supply or said another bias power supply is electrically connected to the second electrode via a capacitor and is separated from said another chuck power supply in a DC manner.

8. The plasma processing apparatus of claim 5, wherein the bias power supply or said another bias power supply and said another chuck power supply are electrically connected to the second electrode via a wiring extending between the upper surface and a bottom surface of the base member.

9. A plasma processing apparatus comprising: a chamber; a substrate support disposed in the chamber; a plasma generator configured to generate plasma in the chamber; a bias power supply configured to generate bias energy for attracting ions from the plasma to a substrate; and a chuck power supply configured to generate a voltage applied to the substrate support to hold the substrate using an electrostatic attractive force, wherein the bias energy is a radio frequency power or a periodically generated voltage pulse, the substrate support includes: a base; and a dielectric part that provides a supporting surface on which a substrate is placed, extends from an upper surface of the base to the supporting surface, and is made of only a dielectric, the supporting surface includes a first region on which the substrate is placed and a second region on which an edge ring is placed, the base includes: a first portion made of a conductive material and disposed below the first region; and a second portion that is made of a conductive material, disposed below the second region, and separated from the first portion, the bias power supply and the chuck power supply are electrically connected to the first portion, and the bias power supply or another bias power supply and another chuck power supply are electrically connected to the second portion.

10. The plasma processing apparatus of claim 9, wherein the second portion includes two portions constituting a bipolar electrode, and said another chuck power supply includes two power supplies respectively connected to the two portions.

11. The plasma processing apparatus of claim 9, wherein the bias power supply is electrically connected to the first portion via a capacitor and is separated from the chuck power supply in a DC manner, and the bias power supply or said another bias power supply is electrically connected to the second portion via a capacitor and is separated from the separate chuck power supply in a DC manner.

12. The plasma processing apparatus of claim 9, wherein the plasma generator includes a radio frequency power supply electrically connected to the first portion of the base.

13. A substrate processing method using the plasma processing apparatus according to claim 1, comprising: placing a substrate on the dielectric part of the substrate support; generating plasma in the chamber using the plasma generator; holding the substrate on the substrate support by

supplying a voltage from the chuck power supply; and attracting ions from the plasma to the substrate by supplying the bias energy from the bias power supply.