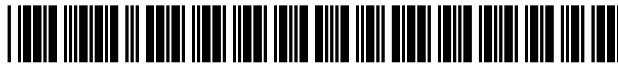

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(45) **Date of Patent: Jan. 2, 2024**

(54) **SUBSTRATE PROCESSING APPARATUS WITH ELECTRONIC HEATER POWERED BY POWER FEEDING COIL**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 608 days.

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

H01L 21/67 (2006.01)
H01L 21/687 (2006.01)
H05B 6/10 (2006.01)

(52) **U.S. Cl.**

CPC .. ***H01L 21/67103*** (2013.01); ***H01L 21/68785*** (2013.01); ***H05B 6/10*** (2013.01); *H01L 21/67023* (2013.01)

(58) **Field of Classification Search**

CPC H01L 21/67103; H01L 21/68785; H01L 21/67023; H01L 21/67051; H01L 21/67248; H01L 21/6875; H01L 21/68792; H01L 21/68764; H05B 6/10; H05B 6/105; H05B 1/0233; H01J 37/32715; H01J 37/32724; H01J 37/32733; H02J 50/12

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2019/0006209 A1* 1/2019 Wieser F25B 21/02

FOREIGN PATENT DOCUMENTS

JP	H6-272872 A	9/1994
JP	2007-335709 A	12/2007
JP	2008-034463 A	2/2008
JP	2019-507952 A	3/2019
WO	2017204083	11/2017

OTHER PUBLICATIONS

Office Action dated May 29, 2023 for application No. JP 2019-190275 with Machine translation attached.

* cited by examiner

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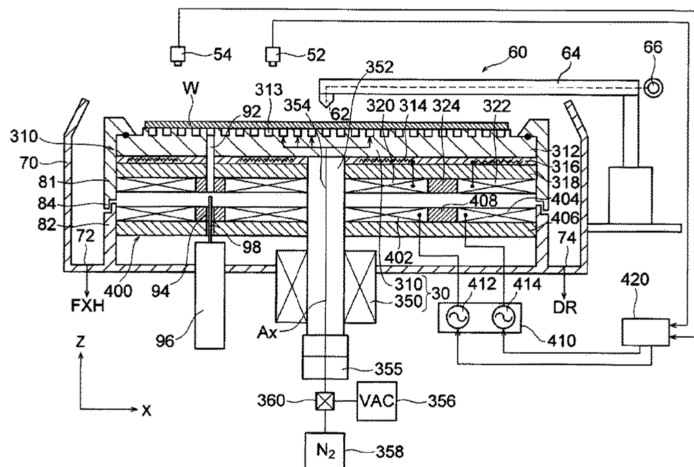
(57) **ABSTRACT**

A substrate processing apparatus includes: a rotary stage configured to hold a substrate; a rotary driver configured to rotate the rotary stage around a rotation axis; at least one electric heater installed in the rotary stage; at least one power receiving coil installed in the rotary stage and electrically connected to the electric heater; at least one power feeding coil installed to face the power receiving coil in a direction of the rotation axis with a gap between the power feeding coil and the power receiving coil; and a radio-frequency power supply unit configured to supply radio-frequency power to the power feeding coil.

14 Claims, 7 Drawing Sheets



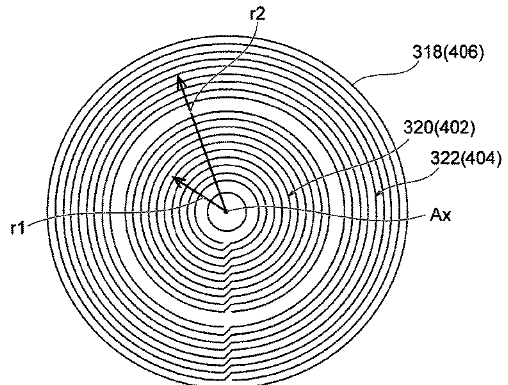


FIG. 1

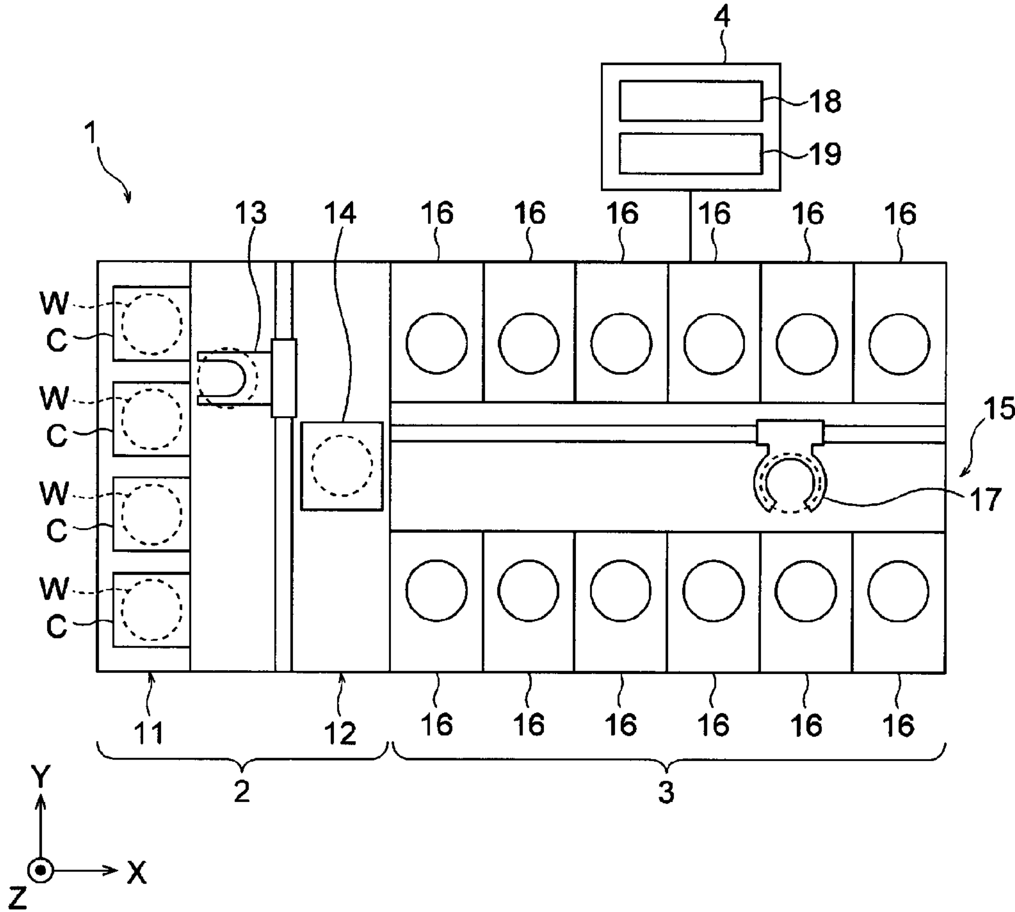


FIG. 2

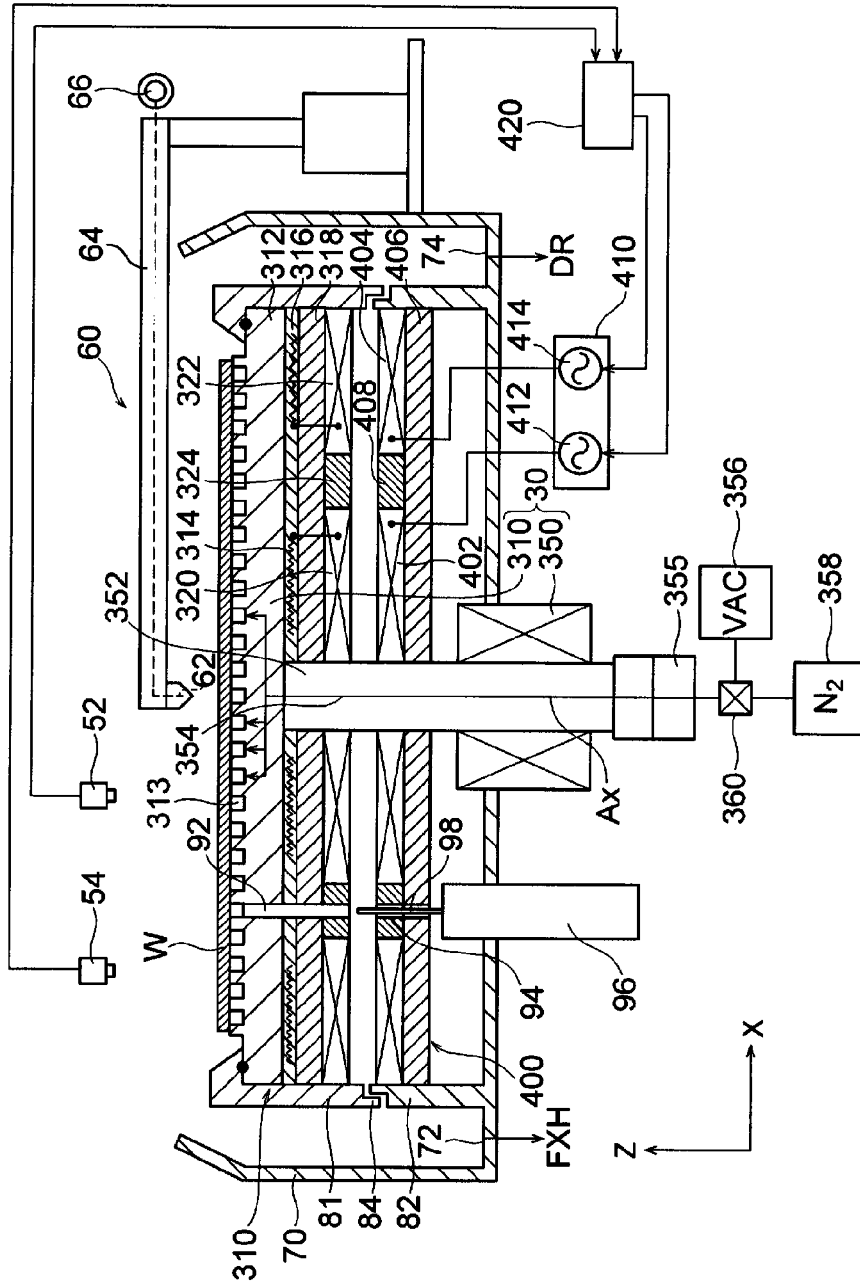


FIG. 3

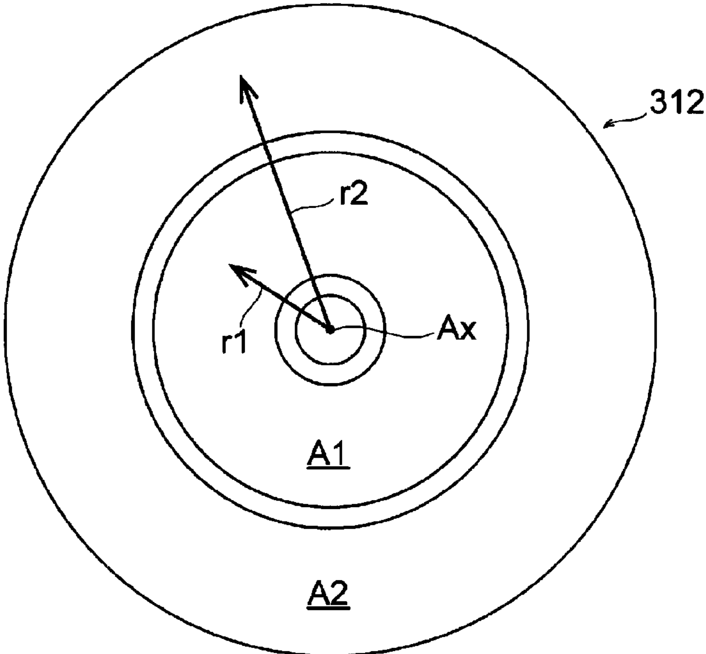


FIG. 4

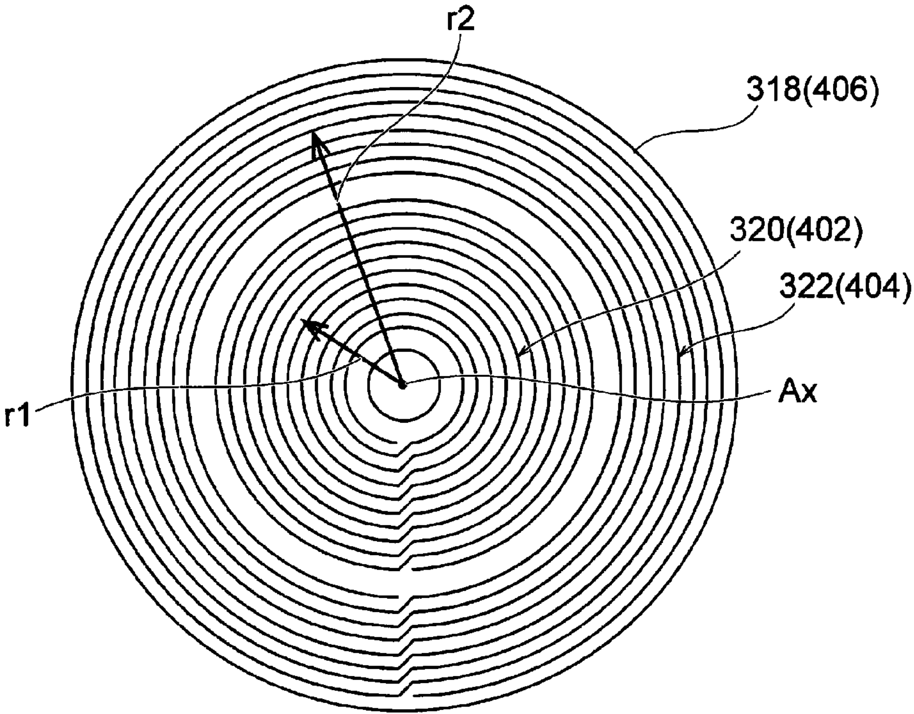


FIG. 5

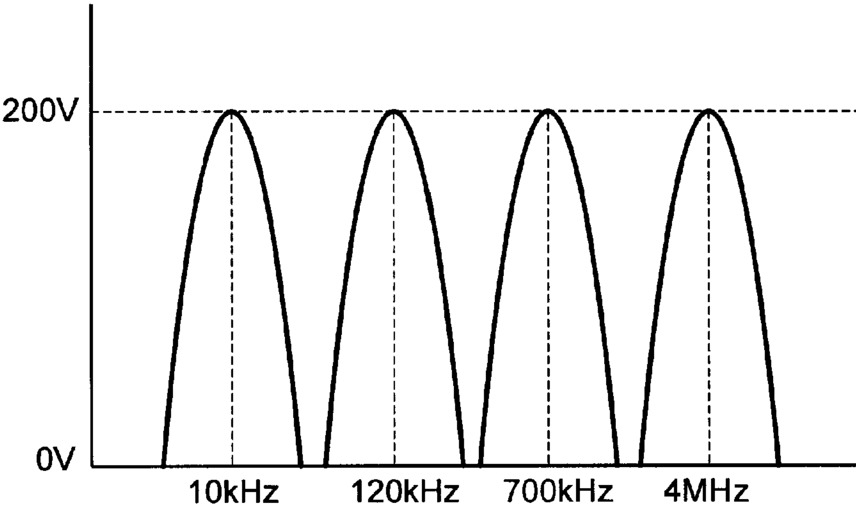


FIG. 6

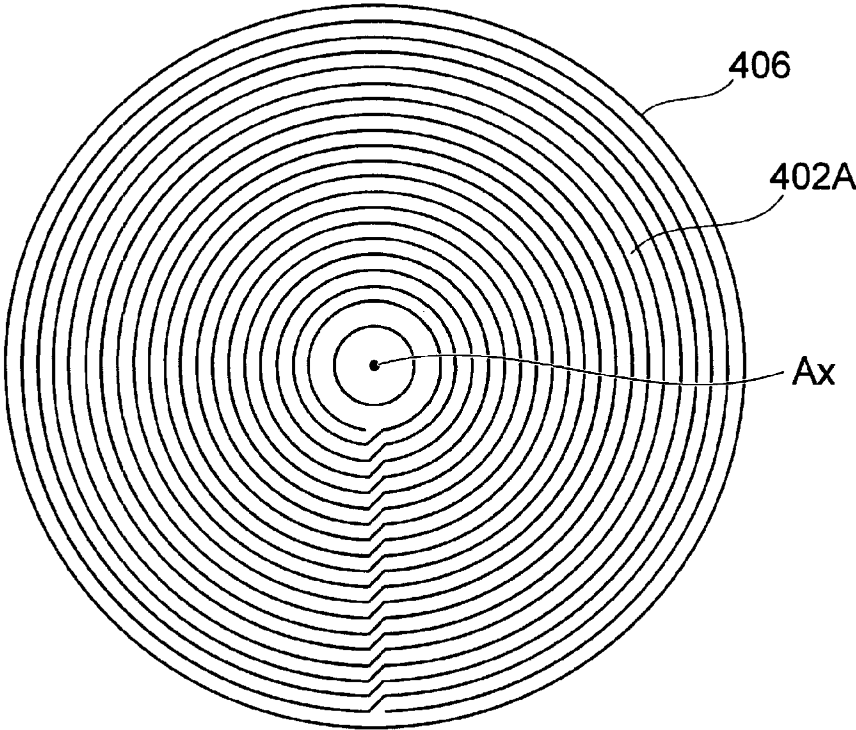
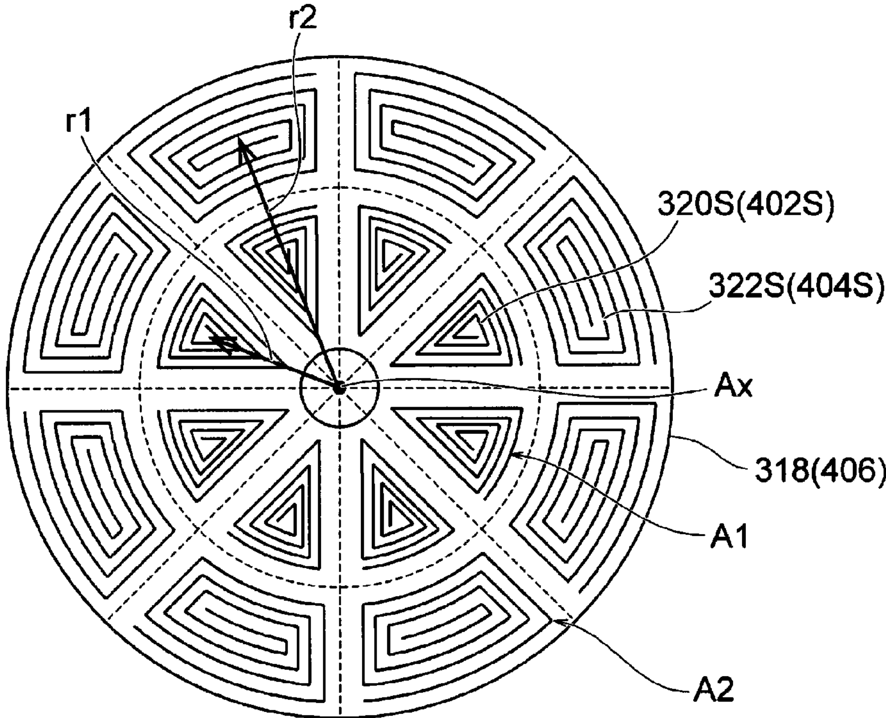


FIG. 7



SUBSTRATE PROCESSING APPARATUS WITH ELECTRONIC HEATER POWERED BY POWER FEEDING COIL

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2019-190275, filed on Oct. 17, 2019, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to a substrate processing apparatus.

BACKGROUND

A process for manufacturing a semiconductor device includes an etching process of etching the surface of a substrate by supplying a chemical liquid to the surface of the substrate while the substrate is being heated and rotated. In this process, it is necessary to rotate the substrate at a high rotation speed while sufficiently heating the substrate, and a substrate processing apparatus configured for that purpose is disclosed in Patent Document 1. This substrate processing apparatus includes a spin chuck, which is provided with a disk-shaped heat generating plate. A coil casing having an annular shape is provided near the bottom of the spin chuck. A plurality of coils are provided inside the coil casing. AC current is supplied to the coil from a coil power supply, thereby generating an alternating magnetic field. The heat generating plate generates heat due to eddy current generated in the heat generating plate to impede the change in the alternating magnetic field, which heats the substrate. An electromagnetic shield plate provided to be in close contact with the top surface of the heat generating plate blocks electromagnetic waves generated by the coil so as to prevent damage to circuit elements already formed on the substrate.

PRIOR ART DOCUMENT

Patent Document

Patent Document 1: Japanese Laid-Open Patent Publication No. 2007-335709

SUMMARY

According to an embodiment of the present disclosure, there is provided a substrate processing apparatus includes: a rotary stage configured to hold a substrate; a rotary driver configured to rotate the rotary stage around a rotation axis; at least one electric heater installed in the rotary stage; at least one power receiving coil installed in the rotary stage and electrically connected to the electric heater; at least one power feeding coil installed to face the power receiving coil in a direction of the rotation axis with a gap between the power feeding coil and the power receiving coil; and a radio-frequency power supply unit configured to supply radio-frequency power to the power feeding coil.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the present disclosure, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the present disclosure.

FIG. **1** is a schematic view illustrating a configuration of a substrate processing system according to an embodiment.

FIG. **2** is a schematic vertical cross-sectional view of a processing unit provided in the substrate processing system of FIG. **1**.

FIG. **3** is a plan view illustrating a heating zone set in a chuck plate of the processing unit of FIG. **2**.

FIG. **4** is a view illustrating an exemplary planar arrangement of a power receiving coil and a power feeding coil.

FIG. **5** is a view for explaining a frequency of radio-frequency power supplied to the power feeding coil.

FIG. **6** is a view for explaining another exemplary planar arrangement of a power feeding coil.

FIG. **7** is a view for explaining another planar arrangement of power receiving coils and power feeding coils.

DETAILED DESCRIPTION

Reference will now be made in detail to various embodiments, examples of which are illustrated in the accompanying drawings. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the present disclosure. However, it will be apparent to one of ordinary skill in the art that the present disclosure may be practiced without these specific details. In other instances, well-known methods, procedures, systems, and components have not been described in detail so as not to unnecessarily obscure aspects of the various embodiments.

An embodiment of a substrate processing apparatus will be described with reference to the accompanying drawings.

FIG. **1** is a schematic view illustrating a configuration of a substrate processing system according to an embodiment. In the following description, in order to clarify positional relationships, an X axis, a Y axis, and a Z axis, which are orthogonal to one another, are defined, and the positive direction of the Z axis is defined as a vertically upward direction.

As illustrated in FIG. **1**, a substrate processing system **1** includes a loading/unloading station **2** and a processing station **3**. The loading/unloading station **2** and the processing station **3** are provided adjacent to each other.

The loading/unloading station **2** includes a carrier placement part **11** and a transport part **12**. A plurality of carriers C, each configured to accommodate a plurality of substrates (semiconductor wafers W in this embodiment) (hereinafter, referred to as "wafers W") in a horizontal state, are placed in the carrier placement part **11**.

The transport part **12** is provided adjacent to the carrier placement part **11**, and includes therein a substrate transport apparatus **13** and a delivery part **14**. The substrate transport apparatus **13** includes a wafer holding mechanism configured to hold a wafer W. In addition, the substrate transport apparatus **13** is capable of moving in the horizontal direction and the vertical direction and rotating about the vertical axis, and thus transports a wafer W between a carrier C and the delivery part **14** using the wafer holding mechanism.

The processing station **3** is provided adjacent to the transport part **12**. The processing station **3** includes a transport part **15** and a plurality of processing units **16**. The plurality of processing units **16** are arranged side by side on both sides of the transport part **15**.

The transport part **15** includes therein a substrate transport apparatus **17**. The substrate transport apparatus **17** includes a wafer holding mechanism configured to hold a wafer W. In addition, the substrate transport apparatus **17** is capable of moving in the horizontal direction and the vertical direction and rotating about the vertical axis. The substrate transport apparatus **17** transports a wafer W between the delivery part **14** and a processing unit **16** using the wafer holding mechanism.

The processing unit **16** performs predetermined substrate processing on the wafer W transported by the substrate transport apparatus **17**.

In addition, the substrate processing system **1** includes a control device **4**. The control device **4** is, for example, a computer, and includes a controller **18** and a storage **19**. In the storage **19**, a program for controlling various processes executed in the substrate processing system **1** is stored. The controller **18** controls the operation of the substrate processing system **1** by reading and executing the program stored in the storage **19**.

Further, such a program may be stored in a computer-readable storage medium, and may be installed in the storage **19** of the control device **4** from the storage medium. The computer-readable storage medium includes, for example, a hard disk (HD), a flexible disk (FD), a compact disc (CD), a magneto-optical disc (MO), and a memory card.

In the substrate processing system **1** configured as described above, first, the substrate transport apparatus **13** of the loading/unloading station **2** removes a wafer W from a carrier C placed in the carrier placement part **11** and places the removed wafer W on the delivery part **14**. The wafer W placed on the delivery part **14** is taken out from the delivery part **14** by the substrate transport apparatus **17** in the processing station **3**, and is loaded into a processing unit **16**.

After being processed by the processing unit **16**, the wafer W loaded into the processing unit **16** is unloaded from the processing unit **16** and placed on the delivery part **14** by the substrate transport apparatus **17**. Then, the processed wafer W placed on the delivery part **14** is returned to the carrier C in the carrier placement part **11** by the substrate transport apparatus **13**.

Next, the configuration of the processing unit **16** will be described with reference to FIG. **2**.

The processing unit **16** includes a substrate holding/rotating mechanism **30** having a heating mechanism. The substrate holding/rotating mechanism **30** includes a rotary stage **310** configured to hold a wafer W in a horizontal orientation, that is, a substrate holder, and an electric motor (a rotary driver) **350** configured to rotate the rotary stage **310** around a vertical axis (a rotation axis Ax). FIG. **2** illustrates the rotation axis Ax and a gas passage **354**, which will be described later, in an overlapping state.

The rotary stage **310** includes a chuck plate **312**, electric heaters **314** and **316**, a ferrite plate **318**, and power receiving coils **320** and **322** in this order from the upper side. A ferrite ring **324** is provided between the power receiving coils **320** and **322**.

The chuck plate **312** is an overall disk-shaped member having a radius larger than that of the wafer W which is a target object. The chuck plate **312** may be formed of, for example, thermally conductive ceramics. Grooves **313** are formed in the top surface of the chuck plate **312**. The wafer W is attached to the top surface of the chuck plate **312** by applying a suction force to the grooves **313** in the state in which the wafer W is placed on the top surface of the chuck plate **312**.

As the electric heaters **314** and **316**, a resistance heater, for example, may be used. As the resistance heater, a polyimide heater, for example, may be used. The electric heaters **314** and **316** are installed on the bottom surface of the chuck plate **312**.

As illustrated in FIGS. **2** and **3**, the electric heater **314** is installed in a first ring-shaped region A**1** in the central region of the bottom surface of the chuck plate **312**. The electric heater **314** mainly heats the region A**1** of the chuck plate **312**. Hereinafter, the electric heater **314** will also be referred to as an "inner heater **314**."

The electric heater **316** is installed in a second ring-shaped area A**2** in the peripheral portion (outside the central portion) of the bottom surface of the chuck plate **312**. The electric heater **316** mainly heats the region A**2** of the chuck plate **312**. Hereinafter, the electric heater **316** will also be referred to as an "outer heater **316**."

In FIG. **3**, "r**1**" means an average of the radius of the inner peripheral edge and the radius of the outer peripheral edge of the region A**1**, and this is called a "first distance," which represents a distance from the rotation axis Ax to the region A**1**. In addition, "r**2**" means an average of the radius of the inner peripheral edge and the radius of the outer peripheral edge of the region A**2**, and this is called a "second distance," which represents a distance from the rotation center Ax to the region A**2**. The second distance r**2** is greater than the first distance r**1**.

The region of the chuck plate **312** covered by one electric heater is also called a "heating zone." In the case of this embodiment, two heating zones (an inner heating zone A**1** and an outer heating zone A**2**) are set. Further, the heat generated by the inner heater **314** also heats the outer heating zone, and the heat generated by the outer heater **316** also heats the inner heating zone. However, if the chuck plate **312** is formed sufficiently thin, it is possible to perform temperature control without considering that the inner heater **314** heats the outer heating zone and the outer heater **316** heats the inner heating zone.

When polyimide heaters are used as the electric heaters **314** and **316**, the electric heaters **314** and **316** may be formed by an inner heater pattern and an outer heater pattern formed on a common polyimide base material. Although not illustrated in FIG. **3**, the heater patterns of the electric heaters **314** and **316** are formed by resistance-heating elements that meander and extend in the regions A**1** and A**2**, respectively.

Instead of the polyimide heaters, another type of electric heater, for example, ceramic heaters, may be used. When the ceramic heaters are used, the resistance-heating elements may be embedded in the chuck plate **312**.

The power receiving coils **320** and **322** may be thin (doughnut-shaped) coils having an axis (coil axis) extending in the vertical direction. The axes of the two coils **320** and **322** described above substantially coincide with the rotation axis Ax. The power receiving coil **320** is installed in the central portion of the bottom surface of the disk-shaped ferrite plate **318**. Hereinafter, the power receiving coil **320** will also be referred to as an "inner power receiving coil **320**." The power receiving coil **322** is installed in the peripheral portion of the bottom surface of the ferrite plate **318**. Hereinafter, the power receiving coil **322** will also be referred to as an "outer power receiving coil **322**."

An annular ferrite ring **324** is installed between the inner power receiving coil **320** and the outer power receiving coil **322**.

When the rotary stage **310** is viewed from directly above, the regions in which the power receiving coils **320** and **322**

are located substantially coincide with the first and second ring-shaped regions A1 and A2 in which the electric heaters **314** and **316** are arranged.

When the processing unit **16** is configured to process a 12-inch wafer, as an example, the inner power receiving coil **320** may have an inner diameter of about 30 mm and an outer diameter of about 70 mm, and the outer power receiving coil **322** may have an inner diameter of about 70 mm (+the width of the ferrite ring) and an outer diameter of about 140 mm.

The winding line of the inner power receiving coil **320** is electrically connected to the inner heater **314**. The winding line of the outer power receiving coil **322** is electrically connected to the outer heater **316**.

The upper end of the rotary shaft **352** of the electric motor **350** is connected to the center of the bottom surface of the chuck plate **312**. The chuck plate **312** is integrally connected to the electric heaters **314** and **316**, the ferrite plate **318**, the power receiving coils **320** and **322**, and the ferrite ring **324**. Therefore, by operating the electric motor **350**, the members **312**, **314**, **316**, **318**, **320**, **322** and **324** integrally rotate around the vertical axis (the rotation axis Ax).

Inside the rotary shaft **352** of the electric motor **350**, the gas passage **354** for transmitting a suction force to the grooves **313** in the top surface of the chuck plate **312** is formed. The gas passage **354** is connected to a vacuum pump **356** and a gas supply source **358** via a rotary joint **355** attached to the lower end of the rotary shaft **352**. A switching valve device **360** including, for example, a three-way valve, is installed in the gas passage **354** in order to select only one of the vacuum pump **356** and the gas supply source **358**.

By suctioning the inner space of the groove **313** by the vacuum pump **356**, the wafer W placed on the chuck plate **312** is attached to the chuck plate **312**. By supplying the suction release gas such as nitrogen gas from the gas supply source **358** to the grooves **313**, the attachment of the wafer W to the chuck plate **312** is released.

An inner power feeding coil **402** and an outer power feeding coil **404** are installed below the inner power receiving coil **320** and the outer power receiving coil **322** with a vertical gap G therebetween. The inner power feeding coil **402** and the outer power feeding coil **404** are thin (doughnut-shaped) coils having an axis (a coil axis) extending in the vertical direction. The axes of the two coils **402** and **404** described above substantially coincide with the rotation axis Ax.

The gap G is preferably 10 mm or less, and more preferably 5 mm or less. From the viewpoint of power feeding efficiency, the size of the gap G is preferably smaller. However, the minimum value of the size of the gap G is limited from the viewpoint of manufacturing precision of the rotary stage **310**, which is a rotating body, and prevention of collision with the power feeding member **400** due to, for example, shaking during operation.

The inner power feeding coil **402** and the outer power feeding coil **404** are installed on the top surface of a disk-shaped ferrite plate **406**. When the rotary stage **310** is viewed from directly above, the arrangement regions of the power feeding coils **402** and **404** are the same or substantially the same as the arrangement regions of the power receiving coils **320** and **322**. Therefore, regardless of the rotation phase (angular position) of the chuck plate **312**, the inner power feeding coil **402** always faces the inner power receiving coil **320** in the direction of the rotation axis Ax, and the outer power feeding coil **404** faces the outer power receiving coil **322** in the direction of the rotation axis Ax.

An annular ferrite ring **408** is installed between the inner power feeding coil **402** and the outer power feeding coil **404**.

In order to simplify the technology below, the assembly of the inner power feeding coil **402**, the outer power feeding coil **404**, the ferrite plate **406**, and the ferrite ring **408** will also be referred to as a "power feeding member **400**."

FIG. **4** schematically illustrates an arrangement of the inner power receiving coil **320** and the outer power receiving coil **322** on the ferrite plate **318**. The arrangement of the inner power feeding coil **402** and the outer power feeding coil **404** on the ferrite plate **406** is the same.

As illustrated in FIG. **2**, the inner power feeding coil **402** and the outer power feeding coil **404** are supplied with radio-frequency power having a frequency of, for example, about 1 kHz to 4 MHz from a radio-frequency power supply unit **410**. The radio-frequency power supply unit **410** has an inner coil power feeding part **412** for supplying radio-frequency power to the inner power feeding coil **402**, and an outer coil power feeding part **414** for supplying radio-frequency power to the outer power feeding coil **404**. By supplying radio-frequency power to the inner power feeding coil **402** and the outer power feeding coil **404**, current flows through the inner power receiving coil **320** and the outer power receiving coil **322** by electromagnetic induction. This current causes the inner heater **314** and the outer heater **316** to generate heat. As described above, power is wirelessly fed to the inner heater **314** and the outer heater **316**.

Hereinafter, in order to simplify the technology, the wireless power feeding system to which the inner power feeding coil **402** and the inner power receiving coil **320** belong will also be referred to as an "inner power feeding channel," and the wireless power feeding system to which the outer power feeding coil **404** and the outer power receiving coil **322** belong will also be referred to as an "outer power feeding channel."

The inner coil power feeding part **412** and the outer coil power feeding part **414** supply radio-frequency power having different frequencies. The resonance frequency of the circuit (resonance circuit) including the inner power receiving coil **320** and the inner heater **314** is adapted to substantially match the frequency of the radio-frequency power supplied by the inner coil power feeding part **412**. In addition, the resonance frequency of the circuit (resonance circuit) including the outer power receiving coil **322** and the outer heater **316** is adapted to substantially match the frequency of the radio-frequency power supplied by the outer coil power feeding part **414**. This makes it possible to prevent mutual interference between the inner power feeding channel and the outer power feeding channel.

The power receiving coils **320** and **322** mainly provide an inductance L in the resonance circuit, and the electric heaters **314** and **316** mainly provide a resistance R in the resonance circuit. In order to adjust the resonance frequency of the resonance circuit, a capacitor having a capacitance C may be provided in the circuit described above. It is preferable to use a capacitor having a fixed capacitance. The resonance frequency may be adjusted according to the known principle of LCR resonance circuits.

FIG. **5** schematically illustrates a relationship between frequency and output voltage of a power receiving coil. For example, the circuit including the inner power receiving coil **320** may be configured to have a characteristic indicated by the leftmost curve, and the circuit including the outer power receiving coil **322** may be configured to have a characteristic indicated by the second curve from the left. As illustrated in FIG. **5**, it is preferable that the frequencies at which the output voltage exhibits a peak value, that is, the resonance

frequencies, are sufficiently spaced apart from each other such that the characteristic curves, in which mutual interference between the power feeding channels is a problem, do not overlap each other. In the case of providing more than two power feeding channels, design may be made based on the same concept.

Ferrite acts as an electromagnetic shield. For this reason, it is possible to prevent the electronic devices constituting the processing unit **16** above the ferrite plate **318** and below the ferrite plate **406** from malfunctioning due to electromagnetic waves. In addition, it is possible to prevent the electronic devices or semiconductor devices already formed on a wafer W from being damaged by an abnormal temperature increase due to radio-frequency induction heating.

By providing the ferrite rings **324** and **408**, it is possible to prevent mutual interference between the inner power feeding channel and the outer power feeding channel. As a result, it becomes possible to individually control the amount of heat generated by the inner heater **314** and the outer heater **316** with high precision.

Since it is difficult for eddy current to flow in the ferrite, abnormal heat generation due to radio-frequency induction heating does not occur in the ferrite plates **318** and **406** and the ferrite rings **324** and **408**, and since it is possible to suppress power loss to a low level, power feeding efficiency is also improved. For example, it has been confirmed through tests that power feeding efficiency of about 90% was obtained.

Above the chuck plate **312** of the rotary stage **310**, non-contact temperature sensors **52** and **54** are provided. The non-contact temperature sensors **52** and **54** may be, for example, infrared (IR) temperature sensors. The temperature sensor **52** is capable of detecting the temperature of the central portion of the top surface of the chuck plate **312** or the central portion of the wafer W placed on the chuck plate **312**, and will also be referred to as an "inner temperature sensor **52**." The temperature sensor **54** is capable of detecting the temperature of the peripheral portion of the top surface of the chuck plate **312** or the peripheral portion of the wafer W placed on the chuck plate **312**, and will also be referred to as an "outer temperature sensor **54**."

The operation of the radio-frequency power supply unit **410** is controlled by a temperature controller **420**. The temperature detected by the inner temperature sensor **52** and the outer temperature sensor **54** are input to the temperature controller **420**. The inner temperature sensor **52**, the outer temperature sensor **54**, and the temperature controller **420** may be connected by a wire. Based on the difference between the temperature detected by the inner temperature sensor **52** and the set temperature, the temperature controller **420** controls feedback of the power feeding to the inner power feeding coil **402** by the inner coil power feeding part **412**. Based on the difference between the temperature detected by the outer temperature sensor **54** and the set temperature, the temperature controller **420** controls feedback of power feeding to the outer power feeding coil **404** by the outer coil power feeding part **414**.

The feedback control may be, for example, PID control or ON/OFF control. As the ON/OFF control, hysteresis control may be used, for example, when the values detected by the temperature sensors **52** and **54** exceed an OFF set temperature (e.g., a target temperature +2 degrees C.), the power feeding is turned off, and when the values detected by the temperature sensor fall below an ON set temperature (e.g. the target temperature −2 degrees C.), the power feeding is turned on. The control of the supplied power in the PID control may be performed by duty control of, for example, pulse width modulation (PWM) (which is microscopically a control involving ON/OFF operation, but is different from the ON/OFF control described above).

In both cases of performing hysteresis (ON/OFF) control and performing duty control, it is preferable to turn on/off the power feeding in the vicinity of zero volts of an AC load voltage. As a result, it is possible to suppress the generation of switching noise and inrush current.

Instead of the non-contact-type temperature sensors **52** and **54** described above, a contact-type temperature sensor (not illustrated) embedded in the chuck plate **312** may be used. In this case, the temperature detected by the contact-type temperature sensor may be transmitted to the temperature controller **420** by a wireless transmission device that operates using the power extracted from at least one of the inner power receiving coil **320** and the outer power receiving coil **322**.

However, in the rotary stage **310**, which rotates at a relatively high speed and is located in a strong electromagnetic field, it is preferable to avoid installation of a device (actuator) that performs electrical operations such as switching, control, and transmission/reception (e.g., SSR or MPU), or a device that performs mechanical operations as much as possible.

The processing unit **16** is provided with a processing liquid supply part **60** configured to supply a processing liquid, such as a chemical liquid (e.g., an etching liquid or a cleaning liquid), a rinsing liquid, a drying solvent, or a drying gas, to a surface (the surface to be processed) of a wafer W held by the substrate holding/rotating mechanism **30**. The processing fluid supply part **60** includes at least one nozzle **62**, at least one nozzle arm **64** (a nozzle moving mechanism) configured to carry and move the nozzle **62**, and a processing fluid supply mechanism **66** configured to supply a processing liquid to the nozzle **62**.

The nozzle arm **64** is capable of moving the carried nozzle **62** between a processing position above the center of the wafer W and a standby position outside the wafer W.

Although not illustrated in detail, the processing liquid supply mechanism **66** includes, for example, a factory power source, a pipe (pipeline) connected to a processing liquid supply source, such as a tank and a cylinder, and a flow control device (e.g., an opening/closing valve, a flow meter, or a flow rate control valve) disposed in the pipe.

The processing unit **16** has a liquid receiving cup **70** installed around the substrate holding/rotating mechanism **30** so as to collect the processing liquid scattered from the rotating wafer W. The liquid receiving cup **70** has an exhaust port **72** for evacuating the internal space in the liquid receiving cup **70**, and a drain port **74** for discharging the liquid from the liquid receiving cup **70**.

The processing unit **16** has a chamber (housing), which is not illustrated in FIG. **2**, and the components illustrated in FIG. **2** are arranged in this chamber. A fan filter unit (FFU) may be installed on the ceiling of the chamber.

An upper protective cover **81** and a lower protective cover **82** are installed to protect the constituent elements of the rotary stage **310** and the constituent elements of the power feeding member **400** from a corrosive atmosphere (e.g., an atmosphere derived from a chemical liquid).

The upper protective cover **81** covers the periphery of the rotary stage **310**, which is a rotating body, and the lower protective cover **82** covers the periphery of the power feeding member **400**, which is a non-rotating body. The lower end of the upper protective cover **81** and the upper end of the lower protective cover **82** are configured to form a non-contact seal **84**, for example, a labyrinth seal, as sche-

matically illustrated in FIG. **2**. This makes it possible to prevent the mist of a processing liquid from entering the space inside the upper protective cover **81** and the lower protective cover **82** from the space outside the upper protective cover **81** and the lower protective cover **82** while enabling the upper protective cover **81** and the lower protective cover **82** to rotate relative to each other.

The mist of the processing liquid may be prevented from entering the space inside the upper protective cover **81** and the lower protective cover **82** from the space outside the upper protective cover **81** and the lower protective cover **82** by increasing the pressure inside the upper protective cover **81** and the lower protective cover **82** by supplying gas to the space inside the upper protective cover **81** and the lower protective cover **82**.

As illustrated in FIG. **2**, the lower end of the lower protective cover **82** may be connected to the liquid receiving cup **70**.

Each of the constituent elements of the rotary stage **310** and the constituent elements of the power feeding member **400** includes one or more, preferably three or more, lift pin holes **92** and **94** (only one of the lift pin holes **92** and only one of the lift pin holes **94** being illustrated in FIG. **2**). When the lift pin holes **92** and **94** penetrate the ferrite as in the exemplary configuration illustrated in FIG. **2**, eddy current having a problematic size is not generated by magnetic flux leaking through the holes having a size similar to that of the lift pine holes **92** and **94**. In the case of adopting a configuration in which the lift pin holes **92** and **94** penetrate the portion in which no ferrite is present, it is preferable to surround at least the outer peripheries of the lift pin holes with a magnetic material (ferrite) in order to suppress the influence of eddy current. A lift pin **98** which is raised and lowered by a linear actuator **96** (e.g., an air cylinder) is inserted into each lift pin hole **94** in the power feeding member **400**. When the rotary stage **310** is positioned at a specific angular position (rotation phase) such that the lift pin holes **92** in the rotary stage **310** and the lift pin holes **94** in the power feeding member **400** are aligned, it is possible to raise and lower the lift pins **98** through the lift pin holes **92** in the rotary stage **310**.

The wafer W placed on the chuck plate **312** can be lifted by raising the tips of the lift pins **98** to a position above the top surface of the chuck plate **312**. In this state, the wafer W can be delivered between the lift pins **98** and the arm of the substrate transport apparatus **17** (see FIG. **1**). The wafer W can be placed on the top surface of the chuck plate **312** by lowering the tips of the lift pins **98** supporting the wafer W to a position below the top surface of the chuck plate **312**.

The liquid processing of a wafer W performed by the processing unit **16** will be briefly described.

The wafer W loaded into the processing unit **16** is attached to the chuck plate **312** by suction. In this state, by operating the electric motor **350**, the wafer W held by the chuck plate **312** is rotated. At this time, power is fed from the radio-frequency power supply unit **410** to the inner power feeding coil **402** and the outer power feeding coil **404**. As a result, a current generated by electromagnetic induction flows from the inner power receiving coil **320** to the inner heater **314** and then from the outer power receiving coil **322** to the outer heater **316**. By the feedback control described above, the temperature of the central portion of the wafer W heated by the inner heater **314** and the temperature of the peripheral portion of the wafer W heated by the outer heater **316** are respectively controlled to desired values.

A processing liquid, such as a chemical liquid, is supplied to the surface of the wafer W from the nozzle **62** of the processing fluid supply part **60** in the central portion of the surface of the rotating wafer W, the temperature of which is controlled, whereby chemical liquid processing is performed on the surface of the wafer W. By moving the nozzle **62**, a liquid application point of the chemical liquid ejected from the nozzle **62** on the wafer surface may be moved (e.g., reciprocated between the central portion and the peripheral portion of the wafer).

After the completion of the chemical liquid processing, the processing liquid supply part **60** may perform a rinsing process by supplying a rinsing liquid (e.g., pure water (DIW)) to the wafer W, and may then perform a drying process (e.g., a centrifugal drying process) of the wafer W. Between the rinsing process and the drying process, a drying fluid replacement process may be performed, in which the rinsing liquid is replaced with a drying fluid such as isopropyl alcohol (IPA). When performing the drying process, IPA and a drying gas, such as nitrogen gas, may be simultaneously supplied to the wafer W.

Heating by the inner heater **314** and the outer heater **316** may be performed only when performing the chemical liquid processing. In order to accelerate drying, heating by the inner heater **314** and the outer heater **316** may be performed during the drying process (that is, when the processing liquid is not supplied to the wafer W).

According to the embodiment described above, it is possible to heat the wafer W by the electric heater through non-contact power feeding from the non-rotating power feeding coil (power transmission coil) to the power receiving coil rotating together with the chuck plate holding the wafer W and the electric heater. A complicated contact-type mechanism for feeding power to the rotating electric heater (e.g., a power feeding mechanism using a rolling bearing or a snap ring) is not necessary.

According to the embodiment described above, it is possible to heat the wafer W through the chuck plate **312**, regardless of whether the rotary stage **310** (a substrate holding part) is rotating or not, and regardless of the rotation speed. Even when the liquid processing of the wafer W is performed at a high temperature, it is possible to perform the liquid processing of the wafer W while rotating the wafer W. Therefore, it is possible to process the wafer W while removing a reaction product from the surface of the wafer W, and thus liquid processing quality can be improved.

According to the embodiment described above, by supplying the chemical liquid at normal temperature to the wafer W which is heated and rotated, it is possible to perform the liquid processing while maintaining the temperature of the interface between the surface of the wafer W and the chemical liquid high. In this case, since it is not necessary to heat the chemical liquid before supplying the same, it is possible to suppress consumption of the chemical liquid.

According to the embodiment described above, since the current controlled through the inner power receiving coil **320** and the outer power receiving coil **322** is supplied to the inner heater **314** and the outer heater **316**, it is possible to control the amount of heat generated by the heaters **314** and **316**, and hence to control the temperature of the wafer W with high precision. According to the embodiment described above, compared to, for example, the case of adopting a method of heating a metal heating member provided in the chuck part by radio-frequency induction heating, it is possible to control the temperature and temperature distribution of the wafer W more precisely. Therefore, it is possible to improve liquid processing quality.

Further, according to the embodiment described above, it is possible to independently control the temperature of the central portion of the wafer and the temperature of the peripheral portion of the wafer using the inner heater **314** and the outer heater **316**. Therefore, by increasing the amount of heat generated by the heater **314** or **316** corresponding to a region of the wafer W, in which the temperature tends to be lower, to be higher than that of the other heater, it is possible to make the temperature at the interface between the wafer surface and the processing liquid uniform in the plane of the wafer W. Therefore, it is possible to improve the in-plane uniformity of processing.

The following are examples of the causes of the temperature difference between the central portion and the peripheral portion of a wafer.

(1) The relative velocity between the atmosphere (e.g., air) surrounding the wafer W and the surface of the wafer W is higher at the peripheral portion where the peripheral velocity (distance r from the rotation center of the wafer in a radial direction×angular velocity ω) is higher. Thus, the peripheral edge of the wafer W is easily cooled.

(2) When a high-temperature processing liquid is supplied to the central portion of the wafer W having a temperature lower than the temperature of the processing liquid, the processing liquid spreads to the peripheral portion of the wafer W while heat is transferred therefrom to the wafer W. Thus, the temperature of the processing liquid decreases toward the peripheral edge.

(3) When supplying a highly volatile processing liquid to the central portion of the wafer W, heat removed from the wafer W by vaporization of the processing liquid increases toward the peripheral edge.

Next, a first modification of the present embodiment described above will be described. In the first modification, as illustrated in FIG. **6**, on the top surface of the ferrite plate **406**, there is provided only one large doughnut-shaped power feeding coil **402**A centered on the rotation axis Ax. Two power receiving coils **320** and **322** described above with reference to FIG. **3** are installed on the bottom surface of the ferrite plate **318**. Electric heaters **314** and **316** are electrically connected to the power receiving coils **320** and **322**, respectively.

When the rotary stage **310** is viewed from directly above, the arrangement regions of the power receiving coils **320** and **322** are included in the arrangement region of the large power feeding coil (the first power feeding coil) **402**A. That is, the large power feeding coil **402**A is arranged to face both the power receiving coils **320** and **322**, regardless of the rotation phase of the rotary stage.

In the first modification, the radio-frequency power supply unit **410** is configured as a radio-frequency power supply unit, the output frequency of which is variable. That is, the radio-frequency power supply unit **410** is configured to be capable of selectively supplying, to the power feeding coil **402**A, a frequency corresponding to (substantially the same as) the resonance frequency of the resonance circuit to which the power receiving coil **320** belongs (a first resonance frequency) and a frequency corresponding to the resonance frequency of the resonance circuit to which the power receiving coil **322** belongs (a second resonance frequency). In this case, the radio-frequency power supply unit **410** may include a first coil power feeding part **412** configured to steadily output the radio-frequency power having the first resonance frequency, a second coil-feeding part **414** configured to steadily output the radio-frequency power having the second resonance frequency, and a switch configured to electrically connect only one of the first coil power feeding part **412** and the second coil power feeding part **414** to the power feeding coil **402**A. Alternatively, the radio-frequency power supply unit **410** may have a single coil power feeding part having a variable output frequency. The radio-frequency power supply unit **410** may include a zero-cross circuit.

It is possible to selectively heat the electric heaters **314** and **316** by switching the frequency output from the radio-frequency power supply unit **410**. By switching the frequency output from the radio-frequency power supply unit **410** at high speed, it is possible to cause the electric heaters **314** and **316** to be heated substantially at the same time. By adjusting the ratio of the energization times of the electric heaters **314** and **316**, it is possible to control the ratio of the amount of heat generated by the electric heaters **314** and **316**.

Next, a second modification will be described. As illustrated in FIG. **7**, the second modification includes a plurality of (eight in the illustrated example) inner power receiving coils **320**S and a plurality of (eight in the illustrated example) outer power receiving coils **322**S.

Like the inner power receiving coil **320** described above, the plurality of inner power receiving coils **320**S are arranged in a ring-shaped region A**1** in which the distance from the rotation axis Ax (the first distance r**1**) is relatively small. Further, the plurality of inner power receiving coils **320**S are arranged at different circumferential positions in the ring-shaped region A**1** at equal intervals in the circumferential direction.

Like the outer power receiving coil **322** described above, the plurality of outer power receiving coils **322**S are arranged in a ring-shaped region A**2** in which the distance from the rotation axis Ax (the first distance r**2**) is relatively large. The plurality of outer power receiving coils **322**S are arranged at different circumferential positions in the ring-shaped region A**2** at equal intervals in the circumferential direction.

In the second modification, one electric heater (not illustrated) is electrically connected to one inner power receiving coil **320**S so as to form one resonance circuit. The resonance frequencies of the resonance circuits belonging to different inner power receiving coils **320**S are different from each other. One electric heater (not illustrated) is electrically connected to one outer power receiving coil **322**S so as to form one resonance circuit. The resonance frequencies of resonance circuits belonging to different outer power receiving coils **322**S are different from each other.

In this second modification, a plurality of recesses having shapes matching the shapes of the power receiving coils **320**S and **322**S and the power feeding coils **402**S and **404**S may be formed on the bottom surface of the ferrite plate **318** and the top surface of the ferrite plate **406**. One coil may be stored in each recess. In this case, the ferrite ring may not be provided.

The radio-frequency power supply unit **410** is installed with one coil power feeding part for one power feeding coil **402**S or **404**S. Different coil power feeding parts supply radio-frequency power of different frequencies.

In the second modification, while the rotary stage **310** is rotating, when the power receiving coils **320**S or **322**S face the power feeding coils **420**S or **404**S supplied with radio-frequency power of a frequency corresponding to the resonance frequency of the resonance circuit, which belongs to the power receiving coil, in the direction of the rotation axis Ax, sufficiently large current flows through the electric heater connected to the power receiving coil.

In addition, in the second modification, by positioning the rotary stage **310** such that the resonance frequency of the power receiving coils facing the power feeding coils matches with the frequency of power fed to the power feeding coils, it is possible to supply sufficiently large current to all of the power receiving coils when the rotation of the rotary stage **310** is stopped.

According to the second modification, it is possible to set a plurality of heating zones along the circumferential direction. Therefore, even if a non-uniform temperature distribution occurs along the circumferential direction of the wafer W, it is possible to eliminate or reduce the same.

When a plurality of heating zones are set at the same radial position as in the second modification, it is preferable to control power feeding from the radio-frequency power supply unit **410** through the temperature controller **420** using a contact-type temperature sensor embedded into the chuck plate **312**.

Various other modifications are possible. For example, the arrangement of the power feeding coil illustrated in FIG. **4** and the arrangement of the power receiving coils illustrated in FIG. **7** may be combined. In this case, in the radio-frequency power supply unit **410**, radio-frequency power is supplied to the inner power feeding coil **402** and the outer power feeding coil **404** illustrated in FIG. **4** from the variable-frequency inner coil power feeding part **412** and outer coil power feeding part **414**.

From the viewpoint of ease of manufacture, when the rotary stage **310** is viewed from above, it is preferable that the heating zone (heater arrangement region) and the power receiving coil arrangement region be the same or substantially the same (see, for example, FIGS. **3** and **4**). However, since the electric heaters and the power receiving coils are connected by a wire, the heaters and coils do not necessarily have to have such an arrangement.

It should be understood that the embodiments disclosed herein are illustrative and are not limiting in all aspects. The above-described embodiments may be omitted, replaced, or modified in various forms without departing from the scope and spirit of the appended claims.

Processing performed on a wafer W is not limited to liquid processing such as wet etching processing or chemical liquid cleaning processing, and may be coating processing for applying a film, such as a resist film or an antireflection film, to the surface of the wafer W. In the case of the coating processing, in addition to applying a film forming liquid while heating the wafer W, it is possible to bake the wafer W, for example, immediately after the film forming liquid is applied while rotating the wafer W.

The substrate which is a target object is not limited to a semiconductor wafer, but may be any of various substrates used in the semiconductor device manufacturing field, such as a glass substrate or a ceramic substrate.

According to the present disclosure, it is possible to control the temperature distribution of a substrate with high precision.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosures. Indeed, the embodiments described herein may be embodied in a variety of other forms. Furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the disclosures. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosures.

What is claimed is:

1. A substrate processing apparatus comprising:
a rotary stage configured to hold a substrate;
a rotary driver configured to rotate the rotary stage around a rotation axis;
at least one electric heater installed in the rotary stage;
at least one power receiving coil installed in the rotary stage and electrically connected to the at least one electric heater;
at least one power feeding coil installed to face the at least one power receiving coil in a direction of the rotation axis with a gap between the at least one power feeding coil and the at least one power receiving coil; and
a radio-frequency power supply unit configured to supply radio-frequency power to the at least one power feeding coil,
wherein the at least one electric heater includes a first heater and a second heater, the at least one power receiving coil includes a first power receiving coil and a second power receiving coil, and the at least one power feeding coil includes a first power feeding coil and a second power feeding coil,
wherein a first resonance circuit including the first heater and the first power receiving coil is formed, a second resonance circuit including the second heater and the second power receiving coil is formed, and a first resonance frequency, which is a resonance frequency of the first resonance circuit, and a second resonance frequency, which is a resonance frequency of the second resonance circuit, are different from each other, and
wherein the radio-frequency power supply unit includes a first power feeding part configured to feed, to the first power feeding coil, radio-frequency power having a frequency corresponding to the first resonance frequency, and a second power feeding part configured to feed, to the second power feeding coil, radio-frequency power having a frequency corresponding to the second resonance frequency.

2. The substrate processing apparatus of claim **1**, wherein the first power receiving coil is a donut-shaped coil arranged in a first ring-shaped region centered on the rotation axis and having a first distance from the rotation axis,
the second power receiving coil is a donut-shaped coil arranged in a second ring-shaped region centered on the rotation axis and having a second distance from the rotation axis, the second distance being greater than the first distance,
the first power feeding coil is a donut-shaped coil arranged at a position facing the first power receiving coil, regardless of a rotation phase of the rotary stage, and
the second power feeding coil is a donut-shaped coil arranged at a position facing the second power receiving coil, regardless of the rotation phase of the rotary stage.

3. The substrate processing apparatus of claim **2**, wherein the first heater is arranged to heat a ring-shaped region on a center side of the rotary stage, and the second heater is arranged to heat a ring-shaped region on a peripheral side of the rotary stage.

4. The substrate processing apparatus of claim **1**, wherein the first power receiving coil and the second power receiving coil are coils respectively arranged in first and second portions, which are located at different circumferential positions in a ring-shaped power receiving coil arrangement region having a first distance from the rotation axis,

the first power feeding coil and the second power feeding coil are coils respectively arranged in third and fourth portions, which are located at different circumferential positions in a ring-shaped power feeding coil arrangement region having the first distance from the rotation axis, and

depending on a rotation phase of the rotary stage, a state in which the first power receiving coil and the first power feeding coil face each other and a state in which the first power receiving coil and the first power feeding coil do not face each other are switched, and a state in which the second power receiving coil and the second power feeding coil face each other and a state in which the second power receiving coil and the second power feeding coil do not face each other are switched.

5. The substrate processing apparatus of claim **1**, wherein the first heater and the second heater are installed to be capable of heating different regions of the rotary stage, and are configured to be capable of heating different regions in a plane of the substrate held on the rotary stage.

6. The substrate processing apparatus of claim **1**, further comprising:

a first ferrite disposed between the first power receiving coil and the second power receiving coil; and

a second ferrite disposed between the first power feeding coil and the second power feeding coil.

7. A substrate processing apparatus comprising:

a rotary stage configured to hold a substrate;

a rotary driver configured to rotate the rotary stage around a rotation axis;

at least one electric heater installed in the rotary stage;

at least one power receiving coil installed in the rotary stage and electrically connected to the at least one electric heater;

at least one power feeding coil installed to face the at least one power receiving coil in a direction of the rotation axis with a gap between the at least one power feeding coil and the at least one power receiving coil; and

a radio-frequency power supply unit configured to supply radio-frequency power to the at least one power feeding coil,

wherein the at least one electric heater includes a first heater and a second heater, the at least one power receiving coil includes a first power receiving coil and a second power receiving coil, and the at least one power feeding coil includes one first power feeding coil configured to feed power to the first power receiving coil and the second power receiving coil,

wherein a first resonance circuit including the first heater and the first power receiving coil is formed, a second resonance circuit including the second heater and the second power receiving coil is formed, and a first resonance frequency, which is a resonance frequency of the first resonance circuit, and a second resonance frequency, which is a resonance frequency of the second resonance circuit, are different from each other, and

wherein the radio-frequency power supply unit is configured to have a variable output frequency such that radio-frequency power having a frequency corresponding to the first resonance frequency and radio-frequency power having a frequency corresponding to the second resonance frequency can be selectively supplied to the first power feeding coil.

8. The substrate processing apparatus of claim **7**, wherein the first power receiving coil is a donut-shaped coil arranged in a first ring-shaped region centered on the rotation axis and having a first distance from the rotation axis,

the second power receiving coil is a donut-shaped coil arranged in a second ring-shaped region centered on the rotation axis and having a second distance from the rotation axis, the second distance being greater than the first distance, and

the first power feeding coil is a donut-shaped coil arranged to face both the first power receiving coil and the second power receiving coil, regardless of a rotation phase of the rotary stage.

9. The substrate processing apparatus of claim **7**, wherein the first power receiving coil and the second power receiving coil are coils respectively arranged in first and second portions, which are located at different circumferential positions in a ring-shaped power receiving coil arrangement region having a first distance from the rotation axis, and

the first power feeding coil is a donut-shaped coil arranged to face both the first power receiving coil and the second power receiving coil, regardless of a rotation phase of the rotary stage.

10. The substrate processing apparatus of claim **7**, further comprising:

a ferrite disposed between the first power receiving coil and the second power receiving coil.

11. A substrate processing apparatus comprising:

a rotary stage configured to hold a substrate;

a rotary driver configured to rotate the rotary stage around a rotation axis;

at least one electric heater installed in the rotary stage;

at least one power receiving coil installed in the rotary stage and electrically connected to the at least one electric heater;

at least one power feeding coil installed to face the at least one power receiving coil in a direction of the rotation axis with a gap between the at least one power feeding coil and the at least one power receiving coil;

a radio-frequency power supply unit configured to supply radio-frequency power to the at least one power feeding coil; and

a ferrite disposed between a power receiving coil arrangement region in which the at least one power receiving coil is arranged and a heater arrangement region in which the at least one electric heater is arranged.

12. A substrate processing apparatus comprising:

a rotary stage configured to hold a substrate;

a rotary driver configured to rotate the rotary stage around a rotation axis;

at least one electric heater installed in the rotary stage;

at least one power receiving coil installed in the rotary stage and electrically connected to the at least one electric heater;

at least one power feeding coil installed to face the at least one power receiving coil in a direction of the rotation axis with a gap between the at least one power feeding coil and the at least one power receiving coil;

a radio-frequency power supply unit configured to supply radio-frequency power to the at least one power feeding coil; and

a ferrite disposed between a power feeding coil arrangement region in which the at least one power feeding coil is arranged and an electric motor constituting the rotary driver.

13. A substrate processing apparatus comprising:

a rotary stage configured to hold a substrate;

a rotary driver configured to rotate the rotary stage around a rotation axis;

at least one electric heater installed in the rotary stage;
at least one power receiving coil installed in the rotary stage and electrically connected to the at least one electric heater;
at least one power feeding coil installed to face the at least one power receiving coil in a direction of the rotation axis with a gap between the at least one power feeding coil and the at least one power receiving coil;
a radio-frequency power supply unit configured to supply radio-frequency power to the at least one power feeding coil;
at least one non-contact-type temperature sensor configured to detect a surface temperature of the rotary stage or a surface temperature of the substrate held on the rotary stage; and
a temperature controller configured to control radio-frequency power output from the radio-frequency power supply unit to the at least one power feeding coil based on the surface temperature detected by the at least one non-contact-type temperature sensor such that a temperature of the rotary stage or a temperature of the substrate reaches a target value.

14. The substrate processing apparatus of claim **13**, wherein the radio-frequency power supply unit includes a zero-cross circuit.

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