

## **[DESCRIPTION]**

### **[Title]**

SUBSTRATE PROCESSING DEVICE, HEATER UNIT, AND SEMICONDUCTOR DEVICE  
MANUFACTURING METHOD

### **[Technical Field]**

[0001]

The present invention relates to a substrate processing apparatus, a heater unit and a method of manufacturing a semiconductor device.

### **[Related Art]**

[0002]

As one of manufacturing processes of a semiconductor device, a substrate processing including a step of vaporizing a liquid source containing hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) to generate a vaporized gas serving as a process gas and a step of supplying the vaporized gas to a substrate in a process chamber may be performed (refer to, for example, patent documents 1 and 2).

### **[Related Art Document]**

#### **[Patent Document]**

[0003]

Patent Document 1: International Publication No. 2014/069826.

Patent Document 2: International Publication No. 2013/070343.

### **[Disclosure]**

#### **[Technical Problem]**

[0004]

When the substrate processing described above is performed, depending on conditions, the vaporized gas supplied into the process chamber may be cooled and liquefied in the process

chamber, or a liquid generated by the liquefaction is heated to cause a rapid reaction. Such a phenomenon may occur when a local low temperature region or a local high temperature region is generated due to non-uniform temperatures of members constituting the process chamber. One of the objects of the present invention is to provide a technique capable of performing heating so as to prevent a local deviation in the temperature of the members constituting the process chamber.

#### **[Technical Solution]**

[0005]

According to one aspect of the present invention, there is provided a substrate processing apparatus including: a reaction tube configured to accommodate a substrate; a lid part configured to close a furnace opening formed at the reaction tube; a heater provided on an outer periphery of a side wall around the furnace opening of the reaction tube; a plurality of temperature sensors configured to respectively measure temperatures at a plurality of positions different from each other at the side wall along a circumferential direction of the side wall; and a controller configured to control the heater based on measured values of the plurality of the temperature sensors.

#### **[Description of Drawings]**

[0006]

FIG. 1 schematically illustrating a vertical cross-section of a vertical type process furnace of a substrate processing apparatus preferably used in an embodiment of the present invention.

FIG. 2 schematically illustrating a horizontal cross-section of a structure around a furnace opening of a reaction tube of the substrate processing apparatus preferably used in the

embodiment of the present invention.

FIG. 3(a) schematically illustrates a vertical cross-section of one example of a heater unit and its periphery.

FIG. 3(b) schematically illustrates a vertical cross-section of the one example of the heater unit taken along the dash-dot line shown in FIG. 3(a) when viewed from the direction “A” shown in FIG. 3(a).

FIG. 4(a) schematically illustrates a vertical cross-section of another example of a heater unit and its periphery.

FIG. 4(b) schematically illustrates a vertical cross-section of the another example of the heater unit taken along the dash-dot line shown in FIG. 4(a) when viewed from the direction “A” shown in FIG. 4(a).

FIG. 5(a) schematically illustrates a vertical cross-section of still another example of a heater unit and its periphery.

FIG. 5(b) schematically illustrates a vertical cross-section of the still another example of the heater unit taken along the dash-dot line shown in FIG. 5(a) when viewed from the direction “A” shown in FIG. 5(a).

FIG. 6 schematically illustrates a vertical cross-section of still another example of the heater unit taken along a plane perpendicular to an extending direction of an exhaust pipe.

FIG. 7 schematically illustrates a vertical cross-section of a soaking sheet.

FIG. 8 schematically illustrates a vertical cross-section of a heater unit showing an installation structure of a side wall temperature sensor attached thereto.

FIG. 9 schematically illustrates a connection structure between heater units.

FIG. 10 is a block diagram schematically illustrating a configuration of a controller and related components of the substrate processing apparatus preferably used in the embodiment of the present invention.

FIG. 11 is a flow chart schematically illustrating a substrate processing according the embodiment of the present invention.

FIG. 12 schematically illustrates temperature monitoring points A through N according the embodiment of the present invention.

FIG. 13 schematically illustrates a configuration according to a comparative example and temperature monitoring points A through N according the comparative example.

FIG. 14 schematically illustrates measurement results of temperatures at the temperature monitoring points A through N according to the embodiment of the present invention and the comparative example.

## **[Detailed Description]**

[0007]

<Embodiment of the Present Invention>

Hereinafter, an embodiment of the present invention will be described with reference to FIGS. 1 and 2.

[0008]

### **(1) Configuration of Substrate Processing Apparatus**

As shown in FIG. 1, a process furnace 202 of a substrate processing apparatus includes a reaction tube 203. The reaction tube 203 is made of a heat resistant material such as quartz ( $\text{SiO}_2$ ) and silicon carbide ( $\text{SiC}$ ), and is configured as a cylindrical member provided with a

furnace opening (opening portion) at a lower end thereof. A process chamber 201 is provided in a hollow cylindrical portion of the reaction tube 203. The process chamber 201 includes a wafer accommodation region A (hereinafter, referred to as a “region A”) serving as a first region where a wafer 200 serving as a substrate is accommodated, and a furnace opening peripheral region B (hereinafter, referred to as a “region B”) serving as a second region provided below the region A in a vertical direction. The region A and the region B are provided in the process chamber 201.

[0009]

A seal cap 219 serving as a lid part capable of airtightly closing a lower end opening of the reaction tube 203 is provided under the reaction tube 203. A rotating mechanism 267 is installed below the seal cap 219. The seal cap 219 is of a disk shape, and is configured such that an upper surface base portion 219a constituting an upper surface side of the seal cap 219 and a lower surface base portion 219b constituting a lower surface side of the seal cap 219 are stacked. For example, the upper surface base portion 219a is made of a non-metallic member such as quartz, and has a thickness of about 10 mm to about 20 mm. For example, the lower surface base portion 219b is made of a metal member such as SUS (stainless steel). A rotating shaft 255 of the rotating mechanism 267 is connected to a boat 217 through the seal cap 219. The rotating mechanism 267 is configured to rotate the wafer 200 accommodated in the boat 217 by rotating the boat 217. A bearing portion 219s of the rotating shaft 255 provided on the rotating shaft 255 is configured as a fluid seal such as a magnetic seal. The seal cap 219 may be elevated or lowered in the vertical direction by a boat elevator 115 installed below the reaction tube 203. The boat elevator 115 is configured as a transfer mechanism that loads (transfers) the boat 217, that is, the wafer 200 into the process chamber 201 or unloads (transfers) the boat 217, that is, the wafer

200 out of the process chamber 201 by moving the seal cap 219 upward or downward.

[0010]

The boat 217 serving as a substrate retainer aligns a plurality of wafers including the wafer 200, for example, from 25 to 200 wafers in the vertical direction and supports the plurality of the wafers in a multi-stage manner, while the plurality of the wafers is horizontally oriented with their centers aligned with each other. That is, the boat 217 supports the plurality of the wafers with predetermined intervals therebetween. The boat 217 is made of a heat resistant material such as quartz and silicon carbide (SiC). The boat 217 includes a top plate 217a and a bottom plate 217b at a top and a bottom thereof. A heat insulator 218 is supported in a multi-stage manner under the boat 217. For example, the heat insulator 218 is made of a heat resistant material such as quartz and SiC, and is configured to suppress the heat conduction between the region A and the region B. The heat insulator 218 may also be considered as a part of the components of the boat 217.

[0011]

A heater 207 serving as a first heating part and a heater 208 serving as a second heating part are provided outside the reaction tube 203. Electric power is supplied from a heater power supply unit 210 to the heaters 207 and 208.

[0012]

The heater 207 is vertically installed so as to surround the region A. The heater 207 is controlled so as to heat the wafer 200 accommodated in the region A to a predetermined temperature in a substrate processing which will be described later.

[0013]

The heater 208 is installed below the heater 207 in the vertical direction so as to

surround the region B. The heater 208 includes a plurality of heater units (that is, heater units 208a through 208d) arranged (divided) along an outer circumferential direction of the reaction tube 203. The heater 208 is controlled to maintain a temperature of a side wall around the furnace opening of the reaction tube 203 and a temperature of a pipe at predetermined temperatures in the substrate processing which will be described later. Hereinafter, the side wall around the furnace opening of the reaction tube 203 is simply referred to as a furnace opening side wall.

[0014]

A temperature sensor protection pipe 263a configured to penetrate the side wall of the reaction tube 203 from an outside to an inside of an inner wall of the reaction tube 203 and to extend along the inner wall of the reaction tube 203 is provided in the process chamber 201. A temperature sensor 263 serving as a temperature detection part is inserted from the outside of the reaction tube 203 and provided in the temperature sensor protection pipe 263a. Based on temperature information detected by the temperature sensor 263, an output of the heater 207 is adjusted. The temperature sensor 263 is constituted mainly by a thermocouple. A plurality of temperature sensors including the temperature sensor 263 and a plurality of temperature sensor protection pipes including the temperature sensor protection pipe 263a may be provided.

[0015]

A gas supply pipe 232a configured to supply a vaporized gas into the process chamber 201 is connected to the side wall of the reaction tube 203. The gas supply pipe 232a penetrates the side wall of the reaction tube 203 in the vicinity of the furnace opening (that is, around the region B) from the outside to the inside of the side wall, and extends close to an upper end of the

reaction tube 203 along the inner wall of the reaction tube 203. A front end of the gas supply pipe 232a is opened to constitute a gas supply port 232p. A plurality of gas supply pipes including the gas supply pipe 232a and having different heights may be provided, and the vaporized gas may be supplied into the process chamber 201 through gas supply ports including gas supply port 232p and provided at each of upper ends of the plurality of the gas supply pipes. A gas generator 250a, a mass flow controller (MFC) 241a serving as a flow rate controller (flow rate control mechanism) and a valve 243a serving as an opening/closing valve are sequentially installed at the gas supply pipe 232a in order from an upstream side to a downstream side of the gas supply pipe 232a. The gas generator 250a is connected to pipes such as a liquid supply pipe configured to supply hydrogen peroxide solution serving as a liquid source and a carrier gas supply pipe configured to supply a carrier gas used to vaporize the liquid.

[0016]

In the present specification, the hydrogen peroxide solution refers to an aqueous solution obtained by dissolving hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) which is a liquid at normal temperature in water ( $\text{H}_2\text{O}$ ) serving as a solvent. For example, the gas generator 250a heats the hydrogen peroxide solution to a predetermined temperature (vaporization temperature) to generate the vaporized gas. The gas generator 250a is configured to generate the vaporized gas by vaporizing the hydrogen peroxide solution or by converting the hydrogen peroxide solution into a mist state. The vaporized gas contains the vaporized  $\text{H}_2\text{O}_2$  or the  $\text{H}_2\text{O}_2$  in the mist state and water vapor ( $\text{H}_2\text{O}$  gas) at predetermined concentrations. The  $\text{H}_2\text{O}_2$  contained in the vaporized gas is a kind of active oxygen, is unstable and easily releases oxygen (O), generates an OH radical, and acts as an oxidizing agent (O source) with a very strong oxidizing power.

[0017]

A vaporized gas supply system is configured mainly by the gas supply pipe 232a, the MFC 241a and the valve 243a.

[0018]

An exhaust pipe 231 configured to exhaust an inner atmosphere of the process chamber 201 is connected to the side wall of the reaction tube 203 in the vicinity of the furnace opening (around the furnace opening). A vacuum pump 246 serving as a vacuum exhausting apparatus is connected to the exhaust pipe 231 through a pressure sensor 245 and an APC (Automatic Pressure Controller) valve 244. The pressure sensor 245 serves as a pressure detector configured to detect an inner pressure of the process chamber 201, and the APC valve 244 serves as a pressure controller. With the vacuum pump 246 in operation, the APC valve 244 may be opened or closed to vacuum-exhaust the process chamber 201 or stop the vacuum exhaust. With the vacuum pump 246 in operation, an opening degree of the APC valve 244 may be adjusted based on pressure information detected by the pressure sensor 245, in order to adjust the inner pressure of the process chamber 201. An exhaust system is constituted mainly by the exhaust pipe 231, the APC valve 244 and the pressure sensor 245. The exhaust system may further include the vacuum pump 246.

[0019]

On the furnace opening side wall, the heat may escape from a part (protruding part) protruding outward from the reaction tube 203 such as the gas supply pipe 232a, the temperature sensor protection pipe 263a and the exhaust pipe 231. Further, it may be difficult to uniformly heat the wafer 200 by the heater due to the presence of the protruding part. Therefore, a low

temperature region may locally arise in the parts such as the furnace opening side wall, the gas supply pipe 232a in the process chamber 201 and the temperature sensor protection pipe 263a. On the other hand, when the output of the heater is increased so as not to generate the local low temperature region, a local high temperature region may occur. According to the present embodiment, the heater 208 is mainly configured as follows to prevent the local low temperature region or the local high temperature region from occurring when the heat escapes or the output of the heater is increased.

[0020]

<Configuration of Heater 208>

The configuration of each of the heater units 208a through 208d constituting the heater 208 will be described.

[0021]

As shown in FIG. 2, the heater unit 208a is arranged to heat a portion (hereinafter, also referred to as a “flat part region”) of the furnace opening side wall wherein the pipes such as the gas supply pipe 232a, the temperature sensor protection pipe 263a and the exhaust pipe 231 are not connected to the flat part region. According to the present embodiment, the heater unit 208a and a heater unit 208a' are provided to heat the flat part region.

[0022]

The heater unit 208b is arranged to heat a peripheral portion around a contact region of the furnace opening side wall, wherein the gas supply pipe 232a is connected to the contact region of the furnace opening side wall, and a peripheral portion around a contact region of the gas supply pipe 232a exposed outside the reaction tube 203, wherein the furnace opening side

wall is connected to the contact region of the gas supply pipe 232a. That is, the heater unit 208b is configured to heat both the side wall of the reaction tube 203 and the gas supply pipe 232a.

[0023]

The heater unit 208c is arranged to heat a peripheral portion around a contact region of the furnace opening side wall, wherein the temperature sensor protection pipe 263a is connected to the contact region of the furnace opening side wall, and a peripheral portion around the contact region of the temperature sensor protection pipe 263a exposed outside the reaction tube 203, wherein the furnace opening side wall is connected to the contact region of the temperature sensor protection pipe 263a. That is, the heater unit 208c is configured to heat both the side wall of the reaction tube 203 and the temperature sensor protection pipe 263a.

[0024]

The heater unit 208d is arranged to heat a peripheral portion around a contact region of the exhaust pipe 231 connected to the reaction tube 203.

[0025]

In addition, hereinafter, the peripheral portions around the contact regions of the furnace opening side wall where the pipes such as the gas supply pipe 232a, the temperature sensor protection pipe 263a and the exhaust pipe 231 are connected may be collectively referred to as a “protruding part region”.

[0026]

As will be described later, each of the heater units 208a through 208c may be configured to be provided with a side wall temperature sensor 303a or 303b capable of measuring an outer peripheral surface temperature of the furnace opening side wall. The heater 208 is provided with at least a plurality of side wall temperature sensors arranged at positions spaced apart from each

other along an outer circumferential direction of the heater 208. By controlling the heater 208 based on the temperatures respectively measured by the plurality of the side wall temperature sensors, it is possible to uniformly heat the side wall of the reaction tube 203 such that a temperature of the side wall of the reaction tube 203 is uniform along the outer circumferential direction. At least two or more side wall temperature sensors may be provided in the heater 208. It is not necessary for all the heater units 208a through 208c to include the side wall temperature sensor.

[0027]

In addition, as will be described later, each of the heater units 208b through 208d may be configured to be provided with a gas supply pipe temperature sensor 304b or an exhaust pipe temperature sensor 304d, which are configured to measure a temperature around the pipe such as the gas supply pipe 232a. By controlling the heater 208 based on the temperatures measured by the temperature sensors around the pipes and heating the pipes connected to the reaction tube 203 individually, it is possible to more uniformly heat the side wall of the reaction tube 203 such that the temperature of the side wall of the reaction tube 203 is heated more uniformly and precisely along the outer circumferential direction.

[0028]

The heater units 208a through 208d are connected to the heater power supply unit 210, and the heater power supply unit 210 is configured to supply the electric power to the heater units 208a through 208d. In addition, the plurality of the side wall temperature sensors are connected to a controller 121 serving as a control device which will be described later, and the controller 121 is configured to individually control the electric power supplied to each of the

heater units 208a through 208d via the heater power supply unit 210 based on temperatures measured by the plurality of the side wall temperature sensors. By individually controlling the temperature of each of the plurality of the heater units 208a through 208d arranged along the outer circumferential direction of the reaction tube 203, it is possible to easily and uniformly heat the furnace opening side wall along the circumferential direction. Each of the heater units 208a through 208d may include an individual heater power supply unit, and each of the individual heater power supply unit may be configured to be controlled by the controller 121.

[0029]

<Heater Unit 208a>

Configurations of the heater unit 208a and its periphery will be described in detail below with reference to FIGS. 3(a) and 3(b). The heater unit 208a is disposed along an outer periphery of the furnace opening side wall. More specifically, the heater unit 208a is placed on a flange constituting the lower end of the reaction tube 203 via an O-ring protection part 273. In addition, a partition part 308 made of a material such as SUS (stainless steel) is provided between the heater unit 208a and the heater 207, and in order to suppress the heat influence from the heater 207 and the heat escape from the heater unit 208a, a heat insulating material 307 is filled between the partition part 308 and the heater unit 208a.

[0030]

A cap heater 209 configured to heat the seal cap 219 is provided on a lower surface of the seal cap 219 so that an upper surface of the seal cap 219 (more specifically, an upper surface of the upper surface base portion 219a) is adjusted to a predetermined temperature (for example, 90 °C). The seal cap 219 includes a relatively small number of protruding structures such as the

gas supply pipe 232a around the furnace opening of the reaction tube 203. Therefore, it is relatively easy to heat the seal cap 219 uniformly with the cap heater 209.

[0031]

An O-ring 220a serving as a sealing member is provided on the upper surface of the upper surface base portion 219a so as to be in contact with the lower end of the reaction tube 203. In addition, an O-ring 220b serving as a sealing member is provided on an upper surface of the lower surface base portion 219b so as to be in contact with a lower surface of the upper surface base portion 219a. A coolant flow path 274 provided in the O-ring protection part 273 and a coolant flow path 270 provided in the lower surface base portion 219b are respectively configured to cool the O-ring 220a and the O-ring 220b so as to prevent the O-ring 220a and the O-ring 220b from being heated above the predetermined temperature.

[0032]

The heater unit 208a is constituted by a heating wire 301a, a heating wire storage part 305 formed as a single body in a block shape and configured to accommodate the heating wire 301a, and a heater cover 306 provided so as to surround the heating wire storage part 305. The heater unit 208a may further include the side wall temperature sensor 303a configured to measure the outer peripheral surface temperature of the furnace opening side wall. The side wall temperature sensor 303a passes through the heating wire storage part 305 and the heater cover 306.

[0033]

The heating wire 301a is constituted by a wire such as a Kanthal wire of a helical shape (or spring shape), and is provided along a circumferential direction of the outer periphery of the

reaction tube 203 at a position facing the outer periphery. The heating wire 301a is constituted by a heating wire or a plurality of heating wires parallel to each other. In order to heat the side wall of the reaction tube 203 uniformly in a height direction thereof, it is preferable to use the plurality of the heating wires arranged in parallel to each other. According to the present embodiment, the heating wire 301a is constituted by four Kanthal wires arranged in parallel to each other. In addition, according to the present embodiment, the heating wire 301a is constituted by the plurality of the heating wires separated from each other, the present embodiment is not limited thereto. For example, four parallel heating wires may be provided by folding a single Kanthal wire a plurality of times.

[0034]

As the heating wire 301a, it is particularly preferable to use a wire (for example, the Kanthal wire) characterized in that a peak wavelength of heat rays radiated by the wire when generating heat at around 80 °C to 100 °C is around 5 μm to 10 μm. The wavelength described above is easily absorbed by quartz and is suitable for efficiently heating the structures made of quartz such as the reaction tube 203 and the gas supply pipe 232a. The same also applies to heating wires 301b, 302b and 302d which will be described later.

[0035]

The heating wire storage part 305 is made of a low thermal conductivity material (that is, the thermal conductivity thereof is 0.3 W / m · K or less) such as a porous shaped industrial alumina board, and is configured to suppress the temperature interference between the heating wires constituting the heating wire 301a. That is, the heating wire storage part 305 functions as a separation member configured to prevent the temperature interference between the heating wires.

[0036]

However, it is generally difficult to completely block the temperature interference between the heating wires constituting the heating wire 301a. Therefore, according to the present embodiment, by configuring the heating wire 301a such that a heat generation amount of the heating wires arranged at an upper and lower ends among the plurality of the heating wires arranged in parallel is greater than a heat generation amount of the other heating wires interposed between the heating wires arranged at the upper and lower ends, it is possible to uniformly heat the side wall of the reaction tube 203 in the height direction thereof. More specifically, it is configured such that the thickness of the heating wires arranged at the upper and lower ends is thinner than the thickness of other heating wires interposed between the heating wires arranged at the upper and lower ends. Thereby, the electric resistance can be made different between each of the heating wires so that the heat generation amount is different between each heating wire when the same current amount is supplied thereto.

[0037]

The electric power supplied by the heater power supply unit 210 to the heating wire 301a is controlled by the controller 121 mainly based on the measured temperature of the side wall temperature sensor 303a. However, in case of not providing the side wall temperature sensor 303a in the heater unit 208a, the electric power supplied to the heating wire 301a may be controlled based on the measured temperature of the side wall temperature sensor provided in another heater unit. In addition, the electric power supplied to the heating wire 301a may be controlled based on both the measured temperature of the sidewall temperature sensor 303a and the measured temperature of the side wall temperature sensor provided in another heater unit.

[0038]

<Heater Unit 208b>

Configurations of the heater unit 208b and its periphery will be described in detail below with reference to FIGS. 4(a) and 4(b). Similar to the heater unit 308a, the heater unit 208b is disposed along the outer periphery of the furnace opening side wall. Components of the heater unit 208b that are the same as the components of the heater unit 308a will be denoted by like reference numerals in FIGS. 4(a) and 4(b), and detailed description thereof will be omitted.

[0039]

The heater unit 208b includes a heating wire 301b and a heating wire 302b, a heating wire storage part 305 configured to accommodate the heating wires 301b and 302b and the gas supply pipe temperature sensor 304b serving as a pipe temperature sensor configured to measure a temperature in the vicinity of the gas supply pipe 232a. In addition, the side wall temperature sensor 303b configured to measure the outer peripheral surface temperature of the furnace opening side wall may be provided similarly to the heater unit 208a. The gas supply pipe temperature sensor 304b may directly measure a temperature of the gas supply pipe 232a itself as long as a temperature state of the gas supply pipe 232a in the vicinity of the side wall of the reaction tube 203 can be grasped.

[0040]

The heating wire 301b is provided along a circumferential direction of the outer periphery of the reaction tube 203 at a position facing the outer periphery, and includes the substantially same configuration as the heating wire 301a. However, the heating wire 301b is different from the heating wire 301a, and the heating wire 301b is disposed only at a position

other than where the gas supply pipe 232a is disposed.

[0041]

The heating wire 302b is constituted by a heating wire or a plurality of heating wires arranged in the vicinity of the gas supply pipe 232a along an extending direction of the gas supply pipe 232a (that is, parallel to the extending direction of the gas supply pipe 232a). When the heating wire 302b is constituted by the plurality of the heating wires, the plurality of the heating wires are arranged so as to surround the gas supply pipe 232a. The heating wire 301b alone can heat only a portion of the gas supply pipe 232a protruding from the side wall of the reaction tube 203 immediately adjacent to the side wall of the reaction tube 203, which makes it difficult to sufficiently heat the gas supply pipe 232a in the extending direction. Therefore, the heat escape from the side wall of the reaction tube 203 to the gas supply pipe 232a may not be prevented. On the other hand, according to the present embodiment, since the heating wire 302b is arranged in parallel to the gas supply pipe 232a, it is possible to uniformly heat the gas supply pipe 232a in the extending direction thereof.

[0042]

The gas supply pipe temperature sensor 304b is inserted into the heating wire storage part 305 in parallel to the gas supply pipe 232a. It is preferable that the gas supply pipe temperature sensor 304b is spaced apart from the plurality of the heating wires of the heating wires 302b by a uniform distance.

[0043]

The heating wire storage part 305 is configured as a member formed as a single body (also referred to as a “storage block”) and configured to accommodate the heating wire 301b and

the heating wire 302b and to suppress the temperature interference between the heating wire 301b and the heating wire 302b. As will be described later, the temperatures (or the electrical power) of the heating wire 301b and the heating wire 302b may be individually controlled by the controller 121, and the side wall of the reaction tube 203 and the gas supply pipe 232a are individually heated by the heating wire 301b and the heating wire 302b. According to the present embodiment, by suppressing the temperature interference between the heating wire 301b and the heating wire 302b, it is possible to easily perform an independent and precise heating control on the side wall of the reaction tube 203 and the gas supply pipe 232a.

[0044]

The electric power supplied by the heater power supply unit 210 to the heating wire 301b and the heating wire 302b is individually controlled by the controller 121. The controller 121 controls the electric power supplied to the heating wire 301b via the heater power supply unit 210 mainly based on the measured temperature of the side wall temperature sensor 303b. In addition, the controller 121 controls the electric power supplied to the heating wire 302b via the heater power supply unit 210 mainly based on the measured temperature of the gas supply pipe temperature sensor 304b. However, the electric power supplied to at least one among the heating wire 301b and the heating wire 302b may be controlled based on both the measured temperature of the sidewall temperature sensor 303b and the measured temperature of the gas supply pipe temperature sensor 304b.

[0045]

<Modified Example of Heater Unit 208b>

According to the present embodiment, the single gas supply pipe 232a is connected to

the protruding part region on the side wall of the reaction tube 203 in which the heater unit 208b is disposed. On the other hand, a modified example in which a plurality of gas supply pipes including the gas supply pipe 232a is connected to the protruding part region where one heater unit is disposed may be conceivable. FIGS. 5(a) and 5(b) schematically illustrate a heater unit 208b-1 according to the modified example and its periphery. Components of the heater unit 208b-1 that are the same as the components of the heater unit 308b and its periphery will be denoted by like reference numerals in FIGS. 5(a) and 5(b), and detailed description thereof will be omitted.

[0046]

In particular, the heating wire 302b of the heater unit 208b-1 is constituted by a heating wire or a plurality of heating wires arranged for each of the plurality of the gas supply pipes including the gas supply pipe 232a. As shown in FIG. 5(b), according to the modified example, the interval between the plurality of the gas supply pipes including the gas supply pipe 232a is narrow. According to a conventional configuration, it is difficult to arrange the heating wires when the interval is narrow. However, according to the modified example, the heating wire 302b is arranged in parallel to the plurality of the gas supply pipes including the gas supply pipe 232a so that the plurality of the gas supply pipes including the gas supply pipe 232a is uniformly heated even when the interval therebetween is narrow. In addition, when the interval is narrow, the heating wire 302b may be arranged between the adjacent gas supply pipes among the plurality of the gas supply pipes including the gas supply pipe 232a so that the plurality of the gas supply pipes including the gas supply pipe 232a may be heated by a single heating wire.

[0047]

The gas supply pipe temperature sensor 304b is provided for at least one of the plurality of the gas supply pipes including the gas supply pipe 232a, and the gas supply pipe temperature sensor 304b may be provided for each of the plurality of the gas supply pipes including the gas supply pipe 232a.

[0048]

<Heater Unit 208c>

Configurations of the heater unit 208c and its periphery are the same as those of the heater unit 208b. The heater unit 208c differs from the heater unit 208b only in that the heater unit 208c is configured to heat the contact region of the temperature sensor protection pipe 263a while the heater unit 208b is configured to heat the contact region of the gas supply pipe 232a.

[0049]

<Heater Unit 208d>

Similar to the heater units 208a through 208c, the heater unit 208d is disposed along the outer periphery of the furnace opening side wall. Configurations of the heater unit 208d and its periphery will be described in detail below with reference to FIG. 6.

[0050]

The heater unit 208d includes a heating wire 302d, a storage part 305a configured to accommodate the heating wire 302d, storage parts 305b and 305c that does not accommodate the heating wire 302d and a soaking sheet 320 provided between an outer periphery of the exhaust pipe 231 and the heating wire 302d to cover the exhaust pipe 231. In addition, similar to the gas supply pipe temperature sensor 304b in the heater unit 208b, the heater unit 208d may include the exhaust pipe temperature sensor 304d serving as a pipe temperature sensor configured to

measure the temperature in the vicinity of the exhaust pipe 231.

[0051]

Similar to the heating wire 302b, the heating wire 302d is constituted by a plurality of heating wires arranged in the vicinity of the exhaust pipe 231 parallel to the exhaust pipe 231. For example, due to reasons such as the installation position of the heater unit, there may be some cases where the heating wire 302d cannot be disposed so as to surround the entire outer peripheral surface of the exhaust pipe 231. Therefore, the heater unit 208d is arranged so that at least one of the plurality of the heating wires extends along only a part of the outer peripheral surface of the exhaust pipe 231 while not installing the plurality of the heating wires at other positions where the plurality of the heating wires cannot be arranged.

[0052]

Similar to the heating wire storage part 305, the storage parts 305a through 305c are made of a low thermal conductivity material. In addition, the storage parts 305a through 305c are divided to facilitate the attachment to the exhaust pipe 231.

[0053]

The soaking sheet 320 is provided to uniformly heat the outer peripheral surface of the exhaust pipe 231 by conducting the heat to the entire outer peripheral surface from at least one of the plurality of the heating wires of the heating wire 302d provided along only the part of the outer peripheral surface of the exhaust pipe 231.

[0054]

As shown in FIG. 7, the soaking sheet 320 is embodied by a structure that a high heat conductive part 322 made of a material such as an alumina sheet and a cushioning part 323 made of a material such as a carbon sheet are stacked in an insulating part 321 made of a material such

as an alumina cloth. The high heat conductive part 322 is disposed on a side close to the heating wire 302d, and is configured to conduct the heat of the heating wire 302d uniformly and entirely along the outer circumferential direction of the exhaust pipe 231. The cushioning part 323 is disposed on a side close to the exhaust pipe 231, and is configured such that the soaking sheet 320 is in close contact with the outer circumferential surface of the exhaust pipe 231. For example, thickness of the soaking sheet 320 is about 3 mm to 5 mm.

[0055]

By providing the soaking sheet 320, it is possible to suppress the occurrence of the local high temperature region on the outer peripheral surface of the exhaust pipe 231 facing the heating wire 302d, and it is also possible to suppress the occurrence of the local low temperature region on the outer peripheral surface of the exhaust pipe 231 where the heating wire 302d is not disposed.

[0056]

The electric power supplied by the heater power supply unit 210 to the heating wire 302d is controlled by the controller 121 mainly based on the measured temperature by the exhaust pipe temperature sensor or the side wall temperature sensor provided in another heater unit.

[0057]

#### <Installation Structure of Side Wall Temperature Sensor>

A front end of the side wall temperature sensor 303a, which is a temperature measurement sensor part of the side wall temperature sensor 303a, is pressed against the furnace opening side wall so as to contact the furnace opening side wall by a structure shown in FIG. 8.

A fixing part 309 is fixed to the heater cover 306, and a spring 310 serving as an elastic member is provided between a protruding portion of the side wall temperature sensor 303a and the fixing part 309. The spring 310 is configured to press the side wall temperature sensor 303a against the side wall of the reaction tube 203 with the fixing part 309 as a fulcrum. The side wall temperature sensor 303b is also installed by a similar structure.

[0058]

<Installation Position of Side Wall Temperature Sensor>

A temperature of the flat part region on the side wall of the reaction tube 203 where the heater unit 208a is installed tends to become high more easily than that of the protruding part region where the heater units 208b, 208c and 208d are installed, and conversely, the temperature of the protruding part region tends to become low more easily than that of the flat part region. This is because the heat escape from the protruding part such as the gas supply pipe 232a hardly occurs in the flat part region, or it is difficult to uniformly heat the protruding part region since an area in which the heating wires 301b and 301c are arranged in the protruding part region is limited.

[0059]

According to the present embodiment, the side wall temperature sensor 303a is provided in the heater unit 208a configured to heat the longest flat part region, a side wall temperature sensor 303a' is provided in the heater unit 208a' disposed at a position facing the heater unit 208a, and the side wall temperature sensor 303b is provided in a heater unit 208b' configured to heat the protruding part region.

[0060]

Since the side wall temperature sensors are arranged at the positions spaced apart from each other as heater control points along the outer circumferential direction of the reaction tube 203, it is possible to individually control the heater units 208a through 208d based on the measured temperatures by the side wall temperature sensors so that the temperature of the side wall of the reaction tube 203 is uniform along the outer circumferential direction.

[0061]

According to the present embodiment, when individually controlling the heater units 208a through 208d, a target temperature value (first target temperature) measured by the side wall temperature sensors 303a and 303a' configured to measure the temperature of the flat part region that tends to become high more easily may preferably set to be lower than a target temperature value (second target temperature) measured by the side wall temperature sensor 303b configured to measure the temperature of the protruding part region that tends to become low more easily. By setting the first target temperature lower than the second target temperature, it is possible to easily control the heater 208 so that the temperature of the side wall of the reaction tube 203 is uniform along the outer circumferential direction thereof.

[0062]

In addition, by mainly controlling the heater units 208a and 208a' such that the temperatures measured by the side wall temperature sensors 303a and 303a' configured to measure the temperature of the flat part region do not exceed a predetermined temperature (for example, a first upper limit temperature described later), it is possible to easily prevent the local high temperature region from occurring on the side wall around the furnace opening.

[0063]

In addition, by mainly controlling the heater unit 208b' such that the temperature measured by the side wall temperature sensors 303b configured to measure the temperature of the protruding part region does not become lower than a predetermined temperature (for example, a first lower limit temperature described later), it is possible to easily prevent the local low temperature region from occurring on the side wall around the furnace opening.

[0064]

Therefore, it is possible to more easily control the heater 208 so that the temperature of the side wall of the reaction tube 203 falls within a predetermined temperature range (for example, the first lower limit temperature or higher and the first upper limit temperature or lower) along the outer circumferential direction thereof.

[0065]

According to the present embodiment, three sidewall temperature sensors are provided. However, by providing at least one sidewall temperature sensor for each of the flat part region where the heater unit 208a is disposed and the protruding part region where the heater units 208b through 208d are disposed, it is possible to obtain the effects described above. However, in order to uniformize the temperature of the side wall of the reaction tube 203 along the outer circumferential direction, it is preferable to provide three or more side wall temperature sensors.

[0066]

#### <Connection Structure between Heater Units>

The heater units 208a through 208d are connected to each other by a connection structure in which crank-shaped end portions are coupled with each other as shown in FIG. 9. In addition, the outer peripheral surfaces of the contact regions of the heater units 208a through

208d are covered with a protective cover 330 made of a material such as SUS (stainless steel). By providing the connection structure described above, it is possible to prevent an inner atmosphere of a space (inner peripheral space) between the heater 208 and the side wall of the reaction tube 203 from leaking to an outer peripheral side of the heater 208, and it is also possible to minimize the temperature drop due to the air flow exchange between the inner peripheral space and the outer peripheral side of the heater 208. A shape of the end portions of each of the heater units is not limited to the crank shape, and may be a combination of shapes with irregularities such as a combination of a convex shape and a concave shape.

[0067]

As shown in FIG. 10, a controller 121 serving as a control device is constituted by a computer including a CPU (Central Processing Unit) 121a, a RAM (Random Access Memory) 121b, a memory device 121c and an I/O port 121d. The RAM 121b, the memory device 121c and the I/O port 121d may exchange data with the CPU 121a through an internal bus 121e. For example, an input/output device 122 such as a touch panel is connected to the controller 121.

[0068]

The memory device 121c is configured by components such as a flash memory and HDD (Hard Disk Drive). For example, a control program for controlling the operation of the substrate processing apparatus and a process recipe containing information on the sequences and the conditions of the substrate processing described later are readably stored in the memory device 121c. The process recipe is obtained by combining steps of the substrate processing described later such that the controller 121 can execute the steps to acquire a predetermine result, and functions as a program. Hereafter, the process recipe and the control program are collectively or individually referred to as a “program”. The process recipe may also be simply

referred to as a “recipe”. In the present specification, the term “program” may indicate only the recipe, may indicate only the control program, or may indicate both of the recipe and the control program. The RAM 121b functions as a memory area (work area) where a program or data read by the CPU 121a is temporarily stored.

[0069]

The I/O port 121d is connected to the above-described components such as the MFC 241a, the valve 243a, the gas generator 250a, the pressure sensor 245, the APC valve 244, the vacuum pump 246, the heater power supply unit 210, the temperature sensor 263, the side wall temperature sensors 303a and 303b, the gas supply pipe temperature sensor 304b, the exhaust pipe temperature sensor 304d, the rotating mechanism 267 and the boat elevator 115

[0070]

The CPU 121a is configured to read the control program from the memory device 121c and execute the read control program. Furthermore, the CPU 121a is configured to read the recipe from the memory device 121c according to an operation command inputted from the input/output device 122. According to the contents of the read recipe, the CPU 121a may be configured to control various operations such as a gas generating operation by the gas generator 250a, a gas flow rate adjusting operation by the MFC 241a, an opening/closing operation of the valve 243a, a pressure adjusting operation by the APC valve 244 based on the pressure sensor 245, and a start and stop of the vacuum pump 246, a power supply amount adjusting operation from the heater power supply unit 210 to the heaters 207 and 208 and the cap heater 209 based on the temperature sensor 263, the side wall temperature sensors 303a and 303b, the gas supply pipe temperature sensor 304b and exhaust pipe temperature sensor 304d, a rotation operation and rotation speed adjusting operation of the boat 217 by the rotating mechanism 267 and an elevating and lowering operation of the boat 217 by the boat elevator 115.

[0071]

The controller 121 may be embodied by installing the above-described program stored in an external memory device 123 into a computer. For example, the external memory device 123 may include a magnetic disk such as a hard disk drive (HDD), an optical disk such as a CD, a magneto-optical disk such as MO, a semiconductor memory such as a USB memory. The memory device 121c or the external memory device 123 may be embodied by a non-transitory computer readable recording medium. Hereafter, the memory device 121c and the external memory device 123 are collectively or individually referred to as the recording medium. In the present specification, the term “recording medium” may indicate only the memory device 121c, may indicate only the external memory device 123, and may indicate both of the memory device 121c and the external memory device 123. Instead of the external memory device 123, a communication means such as the Internet and a dedicated line may be used for providing the program to the computer.

[0072]

## (2) Substrate Processing

Subsequently, an example of the substrate processing performed as a part of manufacturing processes of a semiconductor device will be described with reference to FIG. 11. The substrate processing is performed by using the substrate processing apparatus described above. In the following descriptions, the operations of the components of the substrate processing apparatus are controlled by the controller 121. A film having a silazane bond (-Si-N-) (that is, a polysilazane film) is formed on a surface of a substrate (that is, the wafer 200) that is subject to a predetermined processing. In addition to silicon (Si), the film contains nitrogen (N) and hydrogen (H). The film may further contain carbon (C) and other impurities. In the substrate

processing, the polysilazane film formed on the wafer 200 is modified (oxidized) by supplying the vaporized gas containing  $H_2O_2$  under a relatively low temperature condition.

[0073]

<Substrate Loading Step>

The plurality of the wafers including the wafer 200 is charged (transferred) into the boat 217. The polysilazane film is formed on the surface of each of the plurality of the wafers. Then, as shown in FIG. 1, the boat 217 charged with the plurality of the wafers is elevated by the boat elevator 115 and loaded (transferred) into the process chamber 201. With the boat 217 loaded, the seal cap 219 seals the lower end opening of the reaction tube 203 via the O-ring 220a.

[0074]

<Pressure and Temperature Adjusting Step>

The vacuum pump 246 vacuum-exhausts the inner atmosphere of the process chamber 201 until the inner pressure of the process chamber 201 in which the plurality of the wafers including the wafer 200 is accommodated reaches a desired pressure (modification pressure). In addition, components such as the reaction tube 203, the plurality of the wafers including the wafer 200 accommodated in the process chamber 201 and the seal cap 219 are heated by the heaters 207 and 208 and the cap heater 209.

[0075]

In the pressure and temperature adjusting step, the state of electric conduction from the heater power supply unit 210 to the heater 207 is feedback-controlled based on the temperature information detected by the temperature sensor 263 such that the temperature of the wafer 200 accommodated in the region A reaches a predetermined temperature.

[0076]

In addition, the state of electric conduction from the heater power supply unit 210 to each of the heater units 208a through 208d is feedback-controlled based on the temperature information detected by the temperature sensors (the side wall temperature sensors 303a and 303b, the gas supply pipe temperature sensor 304b and the exhaust pipe temperature sensor 304d) provided in the heater 208 such that the temperature of the side wall of the furnace opening of the reaction tube 203, the temperature of the gas supply pipe 232a, the temperature of the temperature sensor protection pipe 263a and the temperature of the exhaust pipe 231 reach predetermined temperatures (or predetermined temperature distributions), respectively.

[0077]

The feedback control of the heaters 207 and 208 is continuously performed at least until the processing on the wafer 200 is completed. In addition, the rotation of the wafer 200 by the rotating mechanism 267 is started. The operation of the vacuum pump 246 and the heating and rotation of the wafer 200 are continuously performed at least until the processing on the wafer 200 is completed.

[0078]

#### <Modifying Step>

Subsequently, the liquid source and the carrier gas is supplied to the gas generator 250a, and the  $\text{H}_2\text{O}_2$  gas and the vaporized gas containing  $\text{H}_2\text{O}_2$  gas are generated by the gas generator 250a. After the amount and the concentration of the vaporized gas are stabilized, the valve 243a is opened to supply the vaporized gas into the process chamber 201 via the gas supply port 232p while the flow rate of the vaporized gas is controlled (adjusted) by the MFC 241a. The vaporized gas supplied into the process chamber 201 is exhausted through the exhaust pipe 231. That is, in

the modifying step, the vaporized gas is supplied to the wafer 200 in the process chamber 201. As a result, an oxidation reaction occurs on the surface of the wafer 200, and the polysilazane film on the wafer 200 is modified into a silicon oxide film (also referred to as a “SiO film”).

[0079]

After a predetermined time elapses and the modification of the polysilazane film into the SiO film is completed, the valve 243a is closed to stop the supply of the vaporized gas into the process chamber 201.

[0080]

For example, the processing conditions of the modifying step are as follows:

H<sub>2</sub>O<sub>2</sub> concentration of the liquid source: from 20 % to 40 %, preferably from 25 % to 35%;

Vaporization conditions of the liquid source: heating the liquid source at 120 °C to 200 °C under approximately atmospheric pressure;

Modification pressure: 700 hPa to 1,000 hPa (atmospheric pressure, slightly depressurized or slightly pressurized); and

Temperature (modification temperature) of the wafer 200: from 70 °C to 110 °C, preferably from 70 °C to 80 °C.

[0081]

Under the temperature conditions described above, the vaporized gas supplied into the process chamber 201 may be re-liquefied in the process chamber 201, and the liquid generated by the re-liquefaction of the vaporized gas may be stagnant around the furnace opening such as the upper surface of the seal cap 219. In particular, as described above, the local low temperature region may occur in the parts such as the furnace opening side wall, the gas supply pipe 232a in

the process chamber 201 and the temperature sensor protection pipe 263a, and the vaporized gas may be easily re-liquefied by contacting with the local low temperature region.

[0082]

According to the present embodiment, by controlling the heater 208 configured as described above, it is possible to uniformly heat the parts such as the side wall of the furnace opening of the reaction tube 203, and it is also possible to prevent the local low temperature region from occurring. According to the present embodiment, in order to prevent the re-liquefaction of the vaporized gas, a temperature control is performed so that there arises no region whose temperature is lower than a predetermined temperature (first lower limit temperature) on the parts such as the side wall around the furnace opening of the reaction tube 203. The first lower limit temperature may vary depending on conditions such as the concentration of the vaporized gas, but may be set to, for example, 80 °C or higher under the processing conditions described above.

[0083]

In addition, the liquid generated by the re-liquefaction of the vaporized gas tends to be in a state where the  $\text{H}_2\text{O}_2$  exists in a high concentration, that is, a high concentration  $\text{H}_2\text{O}_2$  solution. Further, the stagnant high concentration  $\text{H}_2\text{O}_2$  solution tends to change into a state in which the  $\text{H}_2\text{O}_2$  exists in a higher concentration. The high concentration  $\text{H}_2\text{O}_2$  solution is very reactive and has a strongly corrosive. Therefore, the high concentration  $\text{H}_2\text{O}_2$  solution may cause serious damage to the material of the furnace opening.

[0084]

In addition, when the high concentration  $\text{H}_2\text{O}_2$  solution remaining in the vicinity of the

furnace opening is re-vaporized for some reason, the re-vaporized gas generated thereby contains the  $\text{H}_2\text{O}_2$  at a very high concentration, which may further undermine the safety of work. For example, when the concentration of the  $\text{H}_2\text{O}_2$  contained in the re-vaporized gas exceeds 26 mol % under the atmospheric pressure, the  $\text{H}_2\text{O}_2$  contained in the high concentration the  $\text{H}_2\text{O}_2$  solution is rapidly decomposed into  $\text{O}_2$  gas and  $\text{H}_2\text{O}$  gas to be expanded, and as a result, an explosive decomposition reaction may occur.

[0085]

In the present specification, the term “explosive decomposition reaction” means that the solution containing the  $\text{H}_2\text{O}_2$  is rapidly decomposed into the oxygen ( $\text{O}_2$ ) gas and the water vapor ( $\text{H}_2\text{O}$ ) and expands to cause an explosion, a combustion or a phenomenon close thereto. The explosive decomposition reaction may occur when a temperature of the  $\text{H}_2\text{O}_2$  solution exceeds a predetermined temperature (explosion critical temperature) at a certain concentration and pressure. Therefore, the temperature of the stagnant high concentration  $\text{H}_2\text{O}_2$  solution, which exists due to the re-liquefaction, must be maintained so as not to exceed the explosion critical temperature. The explosion critical temperature varies depending on the concentration of the  $\text{H}_2\text{O}_2$  in the high concentration  $\text{H}_2\text{O}_2$  solution, and specifically, the explosion critical temperature decreases as the concentration of the  $\text{H}_2\text{O}_2$  in the high concentration  $\text{H}_2\text{O}_2$  solution increases. However, when the concentration of the high concentration  $\text{H}_2\text{O}_2$  solution reaches 100%, the explosion critical temperature reaches its lower limit. Therefore, when a process pressure is the atmospheric pressure, the temperature of the high concentration  $\text{H}_2\text{O}_2$  solution is maintained at a temperature lower than 112 °C, which is the explosion critical temperature when the concentration of the high concentration  $\text{H}_2\text{O}_2$  solution is 100%. This makes it possible to reliably

avoid the occurrence of the explosive decomposition reaction.

[0086]

According to the present embodiment, by controlling the heater 208 configured as described above, it is possible to uniformly heat the parts such as the side wall of the furnace opening of the reaction tube 203 so that the high temperature region does not locally arise. According to the present embodiment, in order to prevent the occurrence of the explosive decomposition reaction of the stagnant high concentration  $\text{H}_2\text{O}_2$  solution, the temperature control is performed so that a region whose temperature is higher than a predetermined temperature (first upper limit temperature) does not occur on the parts such as the side wall around the furnace opening of the reaction tube 203. The first upper limit temperature may be set to 112 °C or less when the process pressure is the atmospheric pressure.

[0087]

In addition, the present embodiment may be applied to improve a temperature controllability when performing the temperature control in a temperature region (that is, a temperature region of 120 °C or lower, more preferably 100 °C or lower) in which the influence of the heat transfer by the heat conduction is greater than that of the heat transfer by the radiation. For example, it is preferable to perform the temperature control in a range where the measured temperature such as the temperature detected by the sidewall temperature sensor 303a falls within the temperature ranges described above. In addition, by performing the heating control by the cap heater 209 such that the measured temperature falls within the temperature ranges described above, it is possible to maintain the temperature controllability by the heater 208.

[0088]

#### <Drying Step>

When the modifying step is completed, the heater 207 is controlled to heat the wafer 200 to a temperature higher than the modification temperature described above. By maintaining the temperature higher than the modification temperature, it is possible to gently dry the wafer 200 and the inside of the process chamber 201.

[0089]

#### <Temperature Lowering and Returning to Atmospheric Pressure Step>

After the drying step is completed, the inside of the process chamber 201 is vacuum-exhausted. Thereafter, the inner pressure of the process chamber 201 is returned to the atmospheric pressure. After a predetermined time elapses, the inner temperature of the process chamber 201 is lowered to a predetermined temperature at which the wafer 200 can be unloaded.

[0090]

#### <Substrate Unloading Step>

The seal cap 209 is lowered by the boat elevator 115, and the lower end opening of the reaction tube 203 is opened. The plurality of processed wafers including the wafer 200 is unloaded (transferred) out of the reaction tube 203 through the lower end opening of the reaction tube 203.

[0091]

### (3) Examples

An example and a comparative example of the present embodiment will be described below. As the example of the present embodiment, the temperature control of the heater 208 according to the present embodiment is performed, and temperatures at temperature monitoring points A through N shown in FIG. 12 are measured. The temperature monitoring points A

through H refer to points on the upper surface base portion 219a, and the temperature monitoring points I through N refer to points on the outer peripheral surface of the side wall around the furnace opening. On the other hand, as the comparative example, a temperature control is performed by a heater including the following configuration instead the heater 208 of the present embodiment, and temperatures of temperature monitoring points A, B, E, F, I, K, L and N are measured in the same manner as in the example of the present embodiment. In both the example of the present embodiment and the comparative example, the control is performed by setting target temperatures at the temperature monitoring points A to H to 80 °C to 112 °C.

[0092]

As shown in FIG. 13, a substrate processing apparatus according to the comparative example includes a heater 400 configured to heat the side wall around the furnace opening and a jacket heater 401 configured to heat the protruding part such as the gas supply pipe 232a. The heater 400 does not include the side wall temperature sensor 303a of the present embodiment, and is configured to perform the temperature control only by an output of the heater 400. The jacket heater 401 is provided so as to be wound around each protruding part such as the gas supply pipe 232a, and is mainly provided for the purpose of heating only the protruding part.

[0093]

FIG. 14 schematically illustrates the measurement results of the temperatures at the temperature monitoring points A through N according to the example of the present embodiment and the comparative example. According to the comparative example, the occurrence of the local high temperature region is remarkable, in particular, at the temperature monitoring points A and I with great distances from the protruding part. In addition, at other temperature monitoring

points, the temperatures exceed 112 °C serving as the first upper limit temperature. On the other hand, according to the example of the present embodiment, it is possible to realize a temperature range of 80 °C serving as the first lower limit temperature or more and 112 °C serving as the first upper limit temperature or less at all temperature monitoring points A through N.

[0094]

<Other Embodiments of Present Invention>

While the present invention is described in detail by way of the above-described embodiments and the modified examples, the present invention is not limited thereto. The present invention may be modified in various ways without departing from the gist thereof.

[0095]

For example, while the embodiments are described by way of an example in which the substrate on which the polysilazane film is formed is processed, the present invention is not limited thereto. For example, even when the film to be processed is not the polysilazane film, the same effects as those of the above-described embodiment can be obtained.

[0096]

The above-described embodiments and the modified examples may be appropriately combined. The processing sequences and the processing conditions of the combinations may be substantially the same as those of the above-described embodiments.

**[Industrial Applicability]**

[0097]

According to the present invention, it is possible to provide a technique capable of performing heating so as to prevent a local deviation in a temperature of the members constituting the process chamber from occurring.

### **[Description of Reference Numerals]**

[0098]

200: wafer (substrate)

203: reaction tube

208: heater

232a: gas supply pipe

121: controller

## [CLAIMS]

### [Claim 1]

A substrate processing apparatus comprising:

- a reaction tube configured to accommodate a substrate;
- a lid part configured to close a furnace opening formed at the reaction tube;
- a heater provided on an outer periphery of a side wall around the furnace opening of the reaction tube;
- a plurality of temperature sensors configured to respectively measure temperatures at a plurality of positions different from each other at the side wall along a circumferential direction of the side wall; and
- a controller configured to control the heater based on measured values of the plurality of the temperature sensors.

### [Claim 2]

The substrate processing apparatus of claim 1, wherein the heater comprises a plurality of heater units divided along the circumferential direction of the side wall.

### [Claim 3]

The substrate processing apparatus of claim 2, further comprising a pipe connected to the side wall,

wherein at least one of the plurality of the heater units constitutes a first heater unit configured to heat the pipe together with a portion of the side wall around where the pipe is

connected to the side wall, and

at least another one of the plurality of the heater units constitutes a second heater unit configured to heat another portion of the side wall other than where the pipe is connected to the side wall.

[Claim 4]

The substrate processing apparatus of claim 3, wherein the controller is configured to individually control electric power supplied to the first heater unit and the second heater unit to heat the side wall and the pipe.

[Claim 5]

The substrate processing apparatus of claim 3, wherein the plurality of the temperature sensors comprises:

a first temperature sensor configured to measure a temperature of the portion of the side wall heated by the first heater unit; and

a second temperature sensor configured to measure a temperature of the another portion of the side wall heated by the second heater unit.

[Claim 6]

The substrate processing apparatus of claim 5, wherein the controller is configured to control electric power supplied to the first heater unit so that a measured value of the first temperature sensor to be equal to a first temperature and to control electric power supplied to the second heater unit so that a measured value of the second temperature sensor to be equal to a

second temperature lower than the first temperature.

[Claim 7]

The substrate processing apparatus of claim 3, wherein the first heater unit is configured to heat a plurality of pipes comprising the pipe together with a plurality of portions of the side wall around where the plurality of the pipes comprising the pipe is connected to the side wall.

[Claim 8]

The substrate processing apparatus of claim 3, wherein the pipe comprises at least one selected from a group consisting of a gas supply pipe configured to supply a process gas into the reaction tube, a gas exhaust pipe configured to exhaust an inner atmosphere of the reaction tube and a temperature sensor protection pipe of a tubular shape configured to protect a temperature sensor inserted into the reaction tube.

[Claim 9]

The substrate processing apparatus of claim 3, wherein the first heater unit comprises:  
a first heating wire provided along a circumferential direction of the side wall to face the side wall; and  
a second heating wire provided in vicinity of the pipe along an extending direction of the pipe.

[Claim 10]

The substrate processing apparatus of claim 9, wherein the controller is configured to

individually control electric power supplied to the first heating wire and the second heating wire to heat the side wall and the pipe.

[Claim 11]

The substrate processing apparatus of claim 9, wherein the first heater unit comprises a pipe temperature sensor configured to measure a temperature of the pipe, and

the controller is configured to heat the pipe by controlling electric power supplied to the second heating wire based on a measured value of the pipe temperature sensor.

[Claim 12]

The substrate processing apparatus of claim 9, wherein the first heater unit further comprises a sheet of a high thermal conductivity provided between the second heating wire and the pipe.

[Claim 13]

The substrate processing apparatus of claim 9, wherein the first heater unit further comprises a storage part formed as a single body in a block shape and configured to accommodate the first heating wire and the second heating wire, and

a thermal conductivity of the storage part is equal to or lower than  $0.3 \text{ W / m} \cdot \text{K}$ .

[Claim 14]

The substrate processing apparatus of claim 1, wherein the reaction tube is made of

quartz, and

the heater comprises a heating wire wherein a peak wavelength of heat rays radiated by the heating wire when generating heat at 80 °C to 100 °C is 5 μm to 10 μm.

[Claim 15]

The substrate processing apparatus of claim 1, wherein the controller is configured to control electric power supplied to the heater such that the measured values of the plurality of temperature sensors are equal to or lower than 120 °C.

[Claim 16]

The substrate processing apparatus of claim 1, further comprising a gas supply system configured to supply a gas containing hydrogen peroxide into the reaction tube,

wherein the controller is configured to control electric power supplied to the heater such that the measured values of the plurality of temperature sensors are equal to or higher than 80 °C and are lower than 112 °C.

[Claim 17]

A heater unit provided in a substrate processing apparatus comprising a reaction tube configured to accommodate a substrate, a lid part configured to close a furnace opening formed at the reaction tube, and a pipe connected to a side wall around the furnace opening of the reaction tube,

wherein a plurality of heater units, divided along a circumferential direction of the side

wall and provided on an outer periphery of the side wall, comprises the heater unit,

the heater unit comprising:

a first heating wire provided along the circumferential direction of the side wall to face the side wall; and

a second heating wire provided in vicinity of the pipe along an extending direction of the pipe.

[Claim 18]

A method of manufacturing a semiconductor device, comprising the steps of:

providing a substrate processing apparatus comprising a reaction tube configured to accommodate a substrate, a lid part configured to close a furnace opening formed at the reaction tube, a heater provided on an outer periphery of a side wall around the furnace opening of the reaction tube, and a plurality of temperature sensors configured to respectively measure temperatures at a plurality of positions different from each other at the side wall along a circumferential direction of the side wall;

accommodating the substrate in the reaction tube; and

heating the substrate,

wherein the side wall is heated by controlling electric power supplied to the heater based on measured values of the plurality of the temperature sensors in the step of heating the substrate.