[DESCRIPTION]

[Title]

SUBSTRATE PROCESSING APPARATUS, METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE AND PROGRAM

[Technical Field]

[0001]

The present disclosure relates to a substrate processing apparatus, a method of manufacturing a semiconductor device and a program.

[Related Art]

[0002]

As a part of manufacturing processes of a semiconductor device, a process of forming a film on a substrate using a plurality of nozzles may be performed (refer to, for example, Patent Documents 1 through 4).

[Related Art Document]

[Patent document]

[0003]

Patent Document 1: Japanese Patent No. 4929811

Patent Document 2: Japanese Patent Laid-Open No. 2005-173154

Patent Document 3: Japanese Patent No. 5958231

Patent Document 4: Japanese Patent No. 5658463

[Disclosure]

[Technical Problem]

[0004]

Described herein is a technique capable of improving a uniformity of a film on a surface of a substrate and a uniformity of the film among a plurality of substrates.

[0005]

According to one aspect of the technique of the present disclosure, there is provided a processing apparatus including: a substrate retainer configured to accommodate a plurality of wafers in a horizontal orientation and in a multistage manner, and including: a product wafer support region where a plurality of product wafers are supported; an upper wafer support region provided above the product wafer support region and capable of supporting upper wafers among the plurality of wafers; and a lower wafer support region provided below the product wafer support region and capable of supporting lower wafers among the plurality of wafers; a process chamber in which the substrate retainer is accommodated; a first gas supplier, a second gas supplier and a third gas supplier configured to supply gases into the process chamber; and an exhaust system configured to exhaust an inner atmosphere of the process chamber, wherein the first gas supplier includes a first injector extending vertically along a stacking direction of the plurality of wafers and provided with a plurality of first supply holes capable of supplying a dilution gas therethrough at least to the upper wafer support region, wherein the second gas supplier includes a second injector provided with a plurality of second supply holes capable of supplying a source gas therethrough to the product wafer support region, wherein the third gas supplier includes a third injector extending vertically along the stacking direction of the plurality of wafers and provided with a plurality of third supply holes capable of supplying the dilution gas therethrough at least to the lower wafer support region, and wherein the first injector, the second injector and the third injector are provided in a gas supply area formed at a location in the process chamber facing the exhaust system, and the second injector is interposed between the first injector and the third injector.

[Advantageous Effects]

[0006]

According to some embodiments in the present disclosure, it is possible to improve the uniformity of the film on the surface of the substrate and the uniformity of the film among the plurality of the substrates including the substrate.

[Brief Description of Drawings]

[0007]

FIG. 1 schematically illustrates a vertical cross-section of a vertical type process furnace of a substrate processing apparatus preferably used in an embodiment described herein.

FIG. 2 schematically illustrates a horizontal cross-section of a part of the vertical type process furnace of the substrate processing apparatus preferably used in the embodiment described herein.

FIG. 3 is a block diagram schematically illustrating a configuration of a controller and related components of the substrate processing apparatus preferably used in the embodiment described herein.

FIG. 4(A) schematically illustrates a horizontal cross-section of nozzles and adjacent structures thereof according to the embodiment described herein, and FIG. 4(B) schematically illustrates a positional relationship between the nozzles according to the embodiment described herein and a substrate accommodated in a substrate retainer.

FIG. 5(A) schematically illustrates a horizontal cross-section of nozzles and periphery thereof according to a first modified example described herein, and FIG. 5(B) schematically illustrates a positional relationship between the nozzles according to the first modified example described herein and the substrate accommodated in the substrate retainer.

FIG. 6(A) schematically illustrates a horizontal cross-section of nozzles and periphery thereof according to a second modified example described herein, and FIG. 6(B) schematically illustrates a positional relationship between the nozzles according to

the second modified example described herein and the substrate accommodated in the substrate retainer.

FIG. 7(A) schematically illustrates a horizontal cross-section of nozzles and periphery thereof according to a third modified example described herein, and FIG. 7(B) schematically illustrates a positional relationship between the nozzles according to the third modified example described herein and the substrate accommodated in the substrate retainer.

FIG. 8(A) schematically illustrates a positional relationship between nozzles according to a comparative example described herein and the substrate accommodated in the substrate retainer, and FIG. 8(B) schematically illustrates a positional relationship between the nozzles according to an example of the embodiment described herein and the substrate accommodated in the substrate retainer.

FIG. 9(A) schematically illustrates a simulation result showing a concentration distribution of a silicon source in the vertical type process furnace when the nozzles according to the comparative example shown in FIG. 8(A) are used, and FIG. 9(B) schematically illustrates a thickness distribution of a film on a surface of a product wafer and a thickness distribution of the film among a plurality of product wafers shown in FIG. 9(A).

FIG. 10(A) schematically illustrates a simulation result showing a concentration distribution of a silicon source in the vertical type process furnace when the nozzles according to the example of the embodiment shown in FIG. 8(B) are used, and FIG. 10(B) schematically illustrates a thickness distribution of the film on the surface of the product wafer and a thickness distribution of the film among the plurality of the product wafers shown in FIG. 10(A).

FIG. 11 schematically illustrates evaluation results of thickness distributions of the film on a surface of a substrate (“WiW”) when the film is formed using the nozzles

according to the comparative example and the nozzles according to the example of the embodiment.

FIG. 12 schematically illustrates evaluation results of thickness distributions of the film among a plurality of substrates including the substrate ("WtW") when the film is formed using the nozzles according to the comparative example and the nozzles according to the example of the embodiment.

[Detailed Description]

[0008]

<Embodiment of Present Disclosure>

Hereinafter, an embodiment according to the technique of the present disclosure will be described with reference to FIGS. 1 through 4. A substrate processing apparatus according to the embodiment of the technique is configured as an example of a semiconductor manufacturing apparatus used for manufacturing a semiconductor device.

[0009]

(1) Configuration of Substrate Processing Apparatus

As shown in FIG. 1, a process furnace 202 of the substrate processing apparatus according to the present embodiment includes a heater 207 serving as a heating apparatus (heating structure). The heater 207 is of a cylindrical shape, and is vertically installed while being supported by a heater base (not shown) serving as a support plate. The heater 207 also functions as an activator (exciter) capable of activating (exciting) a process gas by heat.

[0010]

A reaction tube 203 is provided in an inner side of the heater 207 so as to be coaxially aligned with the heater 207. A reaction vessel (which is a process vessel) is constituted by the reaction tube 203. For example, the reaction tube 203 is made of a

heat resistant material such as quartz (SiO_2) and silicon carbide (SiC). The reaction tube 203 is of a cylindrical shape with an open lower end and a closed upper end. The upper end of the reaction tube 203 is closed by a flat wall body. That is, the reaction tube 203 includes a ceiling. A cylindrical portion 209 of a cylindrical shape is provided at a side wall of the reaction tube 203. A gas supply area (buffer) 222 and a gas exhaust area 224 are provided on an outer wall of the cylindrical portion 209. A process chamber 201 is provided in the cylindrical portion 209 of the reaction tube 203. A plurality of wafers including a wafer 200 serving as a substrate is processed in the process chamber 201 under a high temperature and a reduced pressure. The process chamber 201 is configured to accommodate a boat 217 serving as a substrate retainer capable of accommodating (supporting or holding) the plurality of the wafers including the wafer 200 vertically arranged in a horizontal orientation in a multistage manner.

[0011]

The gas supply area 222 is configured to protrude outward from a sidewall of the cylindrical portion 209 of the reaction tube 203. An outer wall of the gas supply area 222 is connected to the outer wall of cylindrical portion 209, and is provided concentrically with the cylindrical portion 209. A diameter of the gas supply area 222 is greater than an outer diameter of the cylindrical portion 209. A lower end of the gas supply area 222 is open, and an upper end of the gas supply area 222 is closed by a flat wall body. Nozzles 304a, 304b and 304c which will be described later are accommodated in the gas supply area 222 along a longitudinal direction (that is, the vertical direction) of the gas supply area 222. A partition wall 252, which serves as a part of the sidewall of the cylindrical portion 209, constitutes a boundary between the gas supply area 222 and the cylindrical portion 209. Gas supply slits 235 are opened on the partition wall 252, and are configured to communicate (connect) with insides of the gas supply area 222 and the process chamber 201. The gas supply slits 235 may be

arranged in a grid pattern including a plurality of rows and a plurality of columns. Preferably, three columns of the gas supply slits 235 are arranged in a circumferential direction of the gas supply area 222 so as to allow each region of the gas supply area 222 to separately communicate with the process chamber 201, and a plurality of rows of the gas supply slits 235, each of which includes three of the gas supply slits 235, are arranged in a manner respectively corresponding to the surfaces (upper surfaces) of the plurality of the wafers including the wafer 200 such that the number of the rows is equal to the number of the wafers counted along the longitudinal direction of the gas supply area 222.

[0012]

The gas exhaust area 224 protrudes outward from a sidewall of the cylindrical portion 209 facing the sidewall where the gas supply area 222 is provided. The plurality of the wafers including the wafer 200 are accommodated in the process chamber 201 between the gas supply area 222 and the gas exhaust area 224. An outer wall of the gas exhaust area 224 is connected to the outer wall of the cylindrical portion 209, and is aligned along a circle which shares its center with the cylindrical portion 209 and whose outer diameter is greater than that of the cylindrical portion 209. A lower end and an upper end of the gas exhaust area 224 are closed by flat wall bodies, respectively.

[0013]

Gas exhaust slits 236 described later are provided on a partition wall 254 which is a wall body constituting a boundary between the gas exhaust area 224 and the cylindrical portion 209. The partition wall 254 serves as a part of the cylindrical portion 209, and a part of an outer surface of the partition wall 254 constitutes a side surface facing the gas exhaust area 224. Thereby, the reaction tube 203 includes a double tube structure where the gas supply area 222 and the gas exhaust area 224 are provided.

[0014]

The lower end of the reaction tube 203 is supported by a manifold 226 of a cylindrical shape. For example, the manifold 226 is made of a metal such as nickel alloy and stainless steel, or is made of a heat resistant material such as quartz (SiO_2) and silicon carbide (SiC). A flange (not shown) is provided at an upper end of the manifold 226, and the lower end of the reaction tube 203 is provided on the flange and supported by the flange. A seal 220a such as an O-ring is provided between the flange and the upper end of the reaction tube 203 to airtightly seal an inside of the reaction tube 203.

[0015]

A seal cap 219 is airtightly attached to a lower end opening of the manifold 226 via a seal 220b such as an O-ring. The seal cap 219 is configured to airtightly seal a lower end opening of the reaction tube 203, that is, the lower end opening of the manifold 226. For example, the seal cap 219 is made of a metal such as nickel alloy and stainless steel, and is of a disk shape. The seal cap 219 may be configured such that an inner surface of the seal cap 219 is covered with a heat resistant material such as quartz (SiO_2) and silicon carbide (SiC).

[0016]

A boat support 218 configured to support the boat 217 is provided on the seal cap 219. The boat support 218 is made of a heat resistant material such as quartz and SiC. The boat support 218 functions not only as a support capable of supporting the boat 217 but also as a heat insulator. The boat 217 is provided vertically on the boat support 218. For example, the boat 217 is made of a heat resistant material such as quartz and SiC. The boat 217 includes a bottom plate that can be placed on the boat support 218 and a top plate provided above the bottom plate. A plurality of support columns are provided between the bottom plate and the top plate. The plurality of the support columns are installed to connect the bottom plate and the top plate. The boat 217 accommodates (supports) the plurality of the wafers including the wafer 200. The

plurality of the wafers is horizontally oriented with predetermined intervals therebetween. That is, the plurality of the wafers is supported by the plurality of the support columns of the boat 217 with their centers aligned with each other. A stacking direction of the plurality of the wafers is equal to an axial direction of the reaction tube 203.

[0017]

A boat rotator 267 configured to rotate the boat 217 is provided at the seal cap 219 opposite to the process chamber 201. A rotating shaft 265 of the boat rotator 267 is connected to the boat support 218 through the seal cap 219. As the boat rotator 267 rotates the boat 217 via the boat support 218, the plurality of the wafers including the wafer 200 supported by the boat 217 are rotated.

[0018]

The seal cap 219 may be elevated or lowered in the vertical direction by a boat elevator 115 provided outside the reaction tube 203. The boat elevator 115 serves as an elevator. As the seal cap 219 is elevated or lowered in the vertical direction by the boat elevator 115, the boat 217 is transferred (loaded) into the process chamber 201 or transferred (unloaded) out of the process chamber 201.

[0019]

Nozzle supports 350, which are configured to support the nozzles (which are injectors) 304a, 304b and 304c, respectively, are installed at the manifold 226 so as to pass through the manifold 226. The nozzle supports 350 are bent in an L shape. According to the present embodiment, for example, three nozzle supports are installed as the nozzle supports 350. For example, the nozzle supports 350 are made of a material such as nickel alloy and stainless steel. Gas supply pipes 310a, 310b and 310c configured to supply gases such as the process gas into the process chamber 201 are connected to first ends of the nozzle supports 350, respectively. The nozzles 304a, 304b

and 304c are connected to second ends of the nozzle supports 350, respectively. For example, the nozzles 304a, 304b and 304c of a pipe shape are made of a heat resistant material such as quartz and SiC.

[0020]

As shown in FIG. 2, inner walls 248 and inner walls 250 are provided inside the gas supply area 222 and the gas exhaust area 224, respectively, so as to divide (partition) inner spaces of each of the gas supply area 222 and the gas exhaust area 224 into a plurality of spaces. The gas supply area 222, the inner walls 248 and the inner walls 250 are made of the same material as the reaction tube 203, for example, a heat resistant material such as quartz or SiC. According to the present embodiment, for example, two inner walls are provided as the inner walls 248 and two inner walls are provided as the inner walls 250. Thus, the inner space of each of the gas supply area 222 and the gas exhaust area 224 is divided into three spaces.

[0021]

The two inner walls 248 are provided so as to divide (partition) the inner space of the gas supply area 222 from a lower end to an upper end thereof into a plurality of spaces. As a result, for example, the three spaces separated by the two inner walls 248 are provided. The nozzles 304a, 304b and 304c are provided in the plurality of the spaces, respectively. Thus, it is possible to suppress the process gas supplied through the nozzles 304a, 304b and 304c from mixing with one another in the gas supply area 222. With the configuration of the gas supply area 222 described above, it is possible to suppress the formation of a film or the generation of by-products in the gas supply area 222 due to the mixing of the process gas in the gas supply area 222. Preferably, the inner walls 248 are provided so as to divide the gas supply area 222 from the lower end to the upper end thereof such that the three spaces separated from one another are provided.

[0022]

Similar to the inner walls 248, the two inner walls 250 are provided so as to divide (partition) the inner space of the gas exhaust area 224 into a plurality of spaces. Preferably, the inner walls 250 are provided so as to divide the gas exhaust area 224 from the vicinity of an upper end thereof to the vicinity of an exhaust port 230 described later. Preferably, when an outer diameter of the outer wall of the gas supply area 222 is the same as the an outer diameter of an outer wall of the gas exhaust area 224, it is possible to suppress the distortion of the reaction tube 203 and to reduce a dead space between the heater 207 and the reaction tube 203. For the same reason, it is preferable that a cross-sectional area of a flow path of the gas in the gas supply area 222 is the same as a cross-sectional area of a flow path of the gas in the gas exhaust area 224. In addition, preferably, a cross-sectional area of the flow path of the gas in each space in the gas supply area 222 is the same as a cross-sectional area of the flow path of the gas in each space in the gas exhaust area 224 facing each space in the gas supply area 222. In addition, preferably, the gas exhaust slits 236 are provided similar to the gas supply slits 235.

[0023]

A source (source gas) containing a predetermined element (main element) constituting a film is supplied into the process chamber 201 from a gas supply source 360b serving as a second gas supply source through the gas supply pipe 310b provided with an MFC 320b and a valve 330b and the nozzle 304b. For example, a halosilane-based gas containing silicon (Si) as the predetermined element and a halogen element may be supplied into the process chamber 201 as the source gas. The source gas refers to a thermally decomposable source gas and a source in a gaseous state. For example, the source gas may refer to the source in the gaseous state under a normal temperature and a normal pressure (atmospheric pressure) or a gas obtained by

vaporizing a source in a liquid state under the normal temperature and the normal pressure. Halosilane refers to silane containing a halogen group. That is, the halogen group includes a halogen element such as chlorine (Cl), fluorine (F), bromine (Br) and iodine (I). As the halosilane-based gas, for example, a source gas containing silicon (Si) and chlorine, that is, a chlorosilane-based gas may be used. The chlorosilane-based gas serves as a silicon source. As the chlorosilane-based gas, for example, hexachlorodisilane (Si_2Cl_6, abbreviated as HCDS) gas may be used.

[0024]

A reactant whose chemical structure (molecular structure) is different from that of the source gas is supplied into the process chamber 201 from a gas supply source 360a serving as a first gas supply source through the gas supply pipe 310a provided with an MFC 320a and a valve 330a and the nozzle 304a. The reactant (also referred to as a "reactive gas") is more difficult to be thermally decomposed or to be activated than the source gas. For example, a hydrogen nitride-based gas, which is a nitriding gas serving as a nitrogen-containing gas, is supplied into the process chamber 201 as the reactant. The hydrogen nitride-based gas serves as a nitrogen (N) source. As the hydrogen nitride-based gas, for example, ammonia (NH_3) gas may be used. The reactant may also be supplied into the process chamber 201 from a gas supply source 360c serving as a third gas supply source through the gas supply pipe 310c provided with an MFC 320c and a valve 330c and the nozzle 304c.

[0025]

An inert gas such as nitrogen gas (N_2 gas) is supplied into the process chamber 201 from a gas supply source 360d, a gas supply source 360e and a gas supply source 360f through gas supply pipes 310d through 310f provided with MFCs 320d through 320f and valves 330d through 330f, respectively, the gas supply pipes 310a through 310c and the nozzles 304a, 304b and 304c. The N_2 gas serves as a purge gas, a carrier

gas or a dilution gas. In addition, the N_2 gas also serves as a control gas which controls a thickness distribution of the film formed on the surface of the wafer 200.

[0026]

A first process gas supply system (also referred to as a "first gas supply system") serving as a reactant supply system is constituted mainly by the gas supply pipe 310a, the MFC 320a, the valve 330a and the nozzle 304a. The first process gas supply system may further include the gas supply source 360a. A second process gas supply system (also referred to as a "second gas supply system") serving as a source supply system is constituted mainly by the gas supply pipe 310b, the MFC 320b, the valve 330b and the nozzle 304b. The second process gas supply system may further include the gas supply source 360b. A third process gas supply system (also referred to as a "third gas supply system") serving as a reactant supply system is constituted mainly by the gas supply pipe 310c, the MFC 320c, the valve 330c and the nozzle 304c. The third process gas supply system may further include the gas supply source 360c. An inert gas supply system is constituted mainly by the gas supply pipes 310a through 310f, the MFCs 320d through 320f, the valves 330d through 330f and the nozzles 304a, 304b and 304c. The inert gas supply system may further include the gas supply sources 360d through 360f.

[0027]

The exhaust port 230 is provided below the gas exhaust area 224. An exhaust pipe 231 is connected to the exhaust port 230. A vacuum pump 246 serving as a vacuum exhauster 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 (pressure meter) to detect an inner pressure of the process chamber 201, and the APC valve 244 serves as a pressure controller (pressure regulator). The vacuum pump 246 is configured to vacuum-exhaust an inner atmosphere of the process

chamber 201 such that the inner pressure of the process chamber 201 reaches a predetermined pressure (vacuum degree). The exhaust pipe 231 at a downstream side of the vacuum pump 246 is connected to a component such as a waste gas processing apparatus (not shown). The APC valve 244 serves as an opening/closing valve. With the vacuum pump 246 in operation, the APC valve 244 may be opened or closed to vacuum-exhaust the process chamber 201 or to stop the vacuum exhaust. With the vacuum pump 246 in operation, by adjusting an opening degree of the APC valve 244, the APC valve 244 is configured to adjust the inner pressure of the process chamber 201 by adjusting a conductance thereof. An exhaust system serving as an exhaust structure 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.

[0028]

A temperature sensor (not shown) serving as a temperature detector is provided in the reaction tube 203. The electrical power supplied to the heater 207 is adjusted based on temperature information detected by the temperature sensor such that a desired temperature distribution of an inner temperature of the process chamber 201 is obtained.

[0029]

As shown in FIG. 3, a controller 280 serving as a control device (control structure) is constituted by a computer including a CPU (Central Processing Unit) 121a, a RAM (Random Access Memory) 121b, a memory 121c and an I/O port 121d. The RAM 121b, the memory 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 280.

[0030]

For example, the memory 121c is configured by components such as a flash memory and HDD (Hard Disk Drive). A control program for controlling the operation

of the substrate processing apparatus or a process recipe containing information on the sequences and conditions of a substrate processing described later is readably stored in the memory 121c. The process recipe is obtained by combining steps of the substrate processing described later such that the controller 280 can execute the steps to acquire a predetermine result, and functions as a program. Hereinafter, the process recipe and the control program are individually or collectively referred to as a "program". The process recipe may also be referred to as a recipe. In the present specification, the term "program" may indicate only the process recipe, may indicate only the control program, or may indicate both of the process 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.

[0031]

The I/O port 121d is connected to the above-described components such as the MFCs 320a through 320f, the valves 330a through 330f, the pressure sensor 245, the APC valve 244, the vacuum pump 246, the heater 207, the boat rotator 267 and the boat elevator 115.

[0032]

The CPU 121a is configured to read the control program from the memory 121c and execute the control program. In addition, the CPU 121a is configured to read the process recipe from the memory 121c according to an instruction such as an operation command inputted from the input/output device 122. According to the contents of the process recipe read from the memory 121c, the CPU 121a may be configured to control various operations such as flow rate adjusting operations for various gases by the MFCs 320a through 320f, opening/closing operations of the valves 330a through 330f, an opening/closing operation of the APC valve 244, a pressure adjusting operation by the APC valve 244 based on the pressure sensor 245, a start and stop of the vacuum pump

246, a temperature adjusting operation of the heater 207 based on the temperature sensor (not shown), an operation of adjusting rotation and rotation speed of the boat 217 by the boat rotator 267 and an elevating and lowering operation of the boat 217 by the boat elevator 115.

[0033]

The controller 280 may be embodied by installing the above-described program stored in an external memory 123 into a computer. For example, the external memory 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 an MO, a semiconductor memory such as a USB memory. The memory 121c or the external memory 123 may be embodied by a non-transitory computer readable recording medium. Hereafter, the memory 121c and the external memory 123 are individually or collectively referred to as recording media. In the present specification, the term “recording media” may indicate only the memory 121c, may indicate only the external memory 123, and may indicate both of the memory 121c and the external memory 123. Instead of the external memory 123, a communication means such as the Internet and a dedicated line may be used for providing the program to the computer.

[0034]

In the process furnace 202 described above, in a state where the plurality of the wafers including the wafer 200 to be batch-processed are stacked in the boat 217 in a multistage manner, the boat 217 is accommodated in the process chamber 201 while being supported by the boat support 218, and the gases are supplied to the plurality of the wafers including the wafer 200 accommodated in the process chamber 201 through the nozzles 304a, 304b and 304c.

[0035]

In recent years, the semiconductor device is three-dimensionalized in order to increase the degree of integration thereof, so that a surface area of a wafer on which a semiconductor film is formed increases. As the surface area of the wafer increases, the consumption of a film-forming gas such as the process gas increases, and a uniformity of the semiconductor film deposited on the wafer may deteriorate.

[0036]

In general, in the vertical type process furnace of the substrate processing apparatus serving as an example of the semiconductor manufacturing apparatus, a plurality of dummy wafers are loaded on an upper portion and a lower portion of the boat 217 accommodating (holding) the plurality of the wafers including the wafer 200 in order to uniformize the temperature of each of the plurality of the wafers arranged in a height direction (vertical direction). Thereby, the film to be grown may be uniformized. However, since a dummy wafer is usually a flat wafer, a surface area of the dummy wafer is different from a surface area of a product wafer on which a pattern is formed. Recently, the surface area of the product wafer may be 50 times or 100 times that of the flat wafer, and the surface area of the product wafer is increasing year by year. However, as the surface area increases, an amount of the consumption of the film-forming gas tends to increase. That is, an amount of the source gas consumed by the dummy wafer and the product wafer is different between a dummy wafer support region (which is a region where the plurality of the dummy wafers are loaded) and a product wafer support region (which is a region where a plurality of product wafers are loaded). Therefore, when the same amount of the source gas is supplied to the plurality of the wafers stacked in the height direction, the source gas is surplus in some location and the source gas is insufficient in other location. Due to the difference in a concentration of the source gas among the plurality of the wafers, it becomes difficult to uniformize the film among the plurality of the wafers.

[0037]

According to the present embodiment, to cope with the problems such as the deterioration of the uniformity of the film quality and the film thickness due to the increase in the surface area of the product wafer, it is possible to improve the uniformity of the film on the surface of the product wafer and the uniformity of the film among the plurality of the product wafers.

[0038]

According to the present embodiment, the three nozzles 304a, 304b and 304c are provided in the gas supply area 222, and are configured to supply two or more types of gas into the process chamber 201. The process chamber 201 is of a cylindrical shape. An inner diameter of the process chamber 201 is 104 % to 108 % of a maximum diameter of the wafer 200 that can be accommodated in the process chamber 201. The nozzles 304a, 304b and 304c are accommodated in the gas supply area 222 formed by protruding a part of the process chamber 201 outward while separated (isolated) from one another. Configurations of the nozzles 304a, 304b and 304c configured to supply the two or more types of the gas into the process chamber 201 will be described with reference to FIGS. 4(A) and 4(B). The nozzle 304a, the nozzle 304b, and the nozzle 304c are used as a first gas supplier, a second gas supplier and a third gas supplier, respectively.

[0039]

FIG. 4(A) schematically illustrates a horizontal cross-section of the nozzles 304a, 304b and 304c and periphery thereof in the product wafer support region where the plurality of the product wafers including a product wafer 200a (also simply referred to as “product wafers 200a”) in the gas supply area 222 is accommodated (held), and FIG. 4(B) schematically illustrates a positional relationship between the nozzles 304a,

304b and 304c and the plurality of the wafers including the wafer 200 accommodated (stacked) in the boat 217 in a multistage manner.

[0040]

The boat 217 includes: the product wafer support region where the product wafers 200a are accommodated (supported) at regular intervals; an upper dummy wafer support region provided above the product wafer support region and capable of supporting the plurality of the dummy wafers including a dummy wafer 200b (also simply referred to as "dummy wafers 200b"); and a lower dummy wafer support region provided below the product wafer support region and capable of supporting dummy wafers 200b. According to the present embodiment, the product wafer 200a refers to a product wafer with a pattern formed thereon, and the dummy wafer 200b refers to a flat bare wafer with no pattern formed thereon, or refers to a wafer whose surface area is between that of the product wafer 200a and that of the bare wafer. That is, one or more dummy wafers are stacked and supported above and below the product wafers 200a, respectively. One or more monitor wafers (for example, three monitor wafers) may be supported in the product wafer support region among the product wafers 200a. The number of the product wafers supported in the product wafer support region may be set to an integral multiple of the number (for example, 25) of wafers that can be accommodated in a wafer carrier such as a FOUP.

[0041]

The nozzles 304a, 304b and 304c are provided in the gas supply area 222 from a lower portion toward an upper portion along the longitudinal direction of the gas supply area 222 (vertical direction). That is, each of the nozzles 304a, 304b and 304c extends in the vertical direction along the boat 217 accommodated in the process chamber 201, and is configured as a long nozzle of a straight tube (straight pipe) shape.

[0042]

In addition, the nozzles 304a, 304b and 304c are arranged in the gas supply area 222 in the vicinity of an outer periphery of the process chamber 201 sequentially in the order of the nozzle 304a, the nozzle 304b, and the nozzle 304c. That is, the nozzle 304a and the nozzle 304c configured to supply the inert gas or the nitriding gas are arranged on both sides of the nozzle 304b configured to supply the source gas. That is, the nozzle 304b configured to supply the source gas is arranged in the center, and the nozzle 304a and the nozzle 304c configured to supply the inert gas or the nitriding gas are arranged such that the nozzle 304b is interposed between the nozzle 304a and the nozzle 304c.

[0043]

The nozzle 304a is connected to the gas supply pipe 310a such that a fluid can flow from the gas supply sources 360a and 360d to a lower end of the nozzle 304a through the gas supply pipe 310a.

[0044]

The nozzle 304b is connected to the gas supply pipe 310b such that a fluid can flow from the gas supply sources 360b and 360e to a lower end of the nozzle 304b through the gas supply pipe 310b.

[0045]

The nozzle 304c is connected to the gas supply pipe 310c such that a fluid can flow from the gas supply sources 360c and 360f to a lower end of the nozzle 304c through the gas supply pipe 310c.

[0046]

A plurality of gas supply holes (also simply referred to as “gas supply holes”) 232a and a plurality of gas supply holes (also simply referred to as “gas supply holes”) 232c configured to supply the gas are provided on side surfaces of the nozzle 304a and the nozzle 304c, respectively. Each of the gas supply holes 232a and the gas supply holes 232c is a small circular hole of a pinhole shape. For example, each of the gas

supply holes 232a and the gas supply holes 232c is constituted by a plurality of openings or a plurality of vertically elongated slits. An upper end of an uppermost gas supply hole among the gas supply holes 232a of the nozzle 304a and an upper end of an uppermost gas supply hole among the gas supply holes 232c of the nozzle 304c are arranged corresponding to an uppermost dummy wafer among the dummy wafers 200b supported in the upper dummy wafer support region. In addition, a lower end of a lowermost gas supply hole among the gas supply holes 232a of the nozzle 304a and a lower end of a lowermost gas supply hole among the gas supply holes 232c of the nozzle 304c are arranged corresponding to a lowermost dummy wafer among the dummy wafers 200b supported in the lower dummy wafer support region. That is, in the nozzle 304a and the nozzle 304c, the gas supply holes 232a and the gas supply holes 232c are provided in the upper dummy wafer support region, the product wafer support region and the lower dummy wafer support region. Preferably, the gas supply holes 232a and the gas supply holes 232c are provided at predetermined intervals so as to correspond to the surfaces (upper surfaces) of the plurality of the wafers including the dummy wafer 200b or correspond to the openings of the gas supply slits 235.

[0047]

A plurality of gas supply holes (also simply referred to as “gas supply holes”) 232b serving as a gas supply port configured to supply the gas are provided on a side surface of the nozzle 304b. An upper end of an uppermost gas supply hole among the gas supply holes 232b of the nozzle 304b is arranged lower than a lowermost dummy wafer among the dummy wafers 200b supported in the upper dummy wafer support region. In addition, a lower end of a lowermost gas supply hole among the gas supply holes 232b of the nozzle 304b is arranged higher than an uppermost dummy wafer among the dummy wafers 200b supported in the lower dummy wafer support region. That is, on the side surface of the nozzle 304b, the gas supply holes 232b are provided

in the product wafer support region, but are not provided in the upper dummy wafer support region and the lower dummy wafer support region. In other words, opening areas of the gas supply holes 232b provided on the side surface of the nozzle 304b are reduced so that the source gas is not supplied to the dummy wafer support region.

[0048]

The gas supply holes 232a, the gas supply holes 232b and the gas supply holes 232c are opened so as to face a center of the reaction tube 203.

[0049]

(2) Substrate Processing

Hereinafter, an exemplary sequence (film-forming sequence) of the substrate processing (film-forming process) of forming a film on the wafer 200 serving as a substrate, which is a part of manufacturing processes of a semiconductor device, will be described. The exemplary sequence is performed by using the above-described substrate processing apparatus. Hereinafter, the operations of the components of the substrate processing apparatus are controlled by the controller 280.

[0050]

The substrate processing will be described by way of an example in which a silicon nitride film (Si_3N_4 film) is formed on the product wafer 200a serving as the wafer 200 by supplying the silicon source gas (source gas) and the nitriding gas in accordance with the following film-forming sequence. For example, a pattern whose surface area is large and at which a concave-convex structure is formed is provided on a surface of the product wafer 200a. Hereinafter, the description of the wafer 200 mainly refers to the product wafer 200a.

[0051]

In the present specification, the term “wafer” may refer to “a wafer itself” or may refer to “a wafer and a stacked structure (aggregated structure) of a predetermined

layer (or layers) or a film (or films) formed on a surface of the wafer". In the present specification, the term "a surface of a wafer" may refer to "a surface of a wafer itself" or may refer to "a surface of a predetermined layer or a film formed on a wafer". Thus, in the present specification, "forming a predetermined layer (or film) on a wafer" may refer to "forming a predetermined layer (or film) on a surface of a wafer itself" or may refer to "forming a predetermined layer (or film) on a surface of another layer or another film formed on a wafer". In the present specification, the term "substrate" and "wafer" may be used as substantially the same meaning. That is, the term "substrate" may be substituted by "wafer" and vice versa.

[0052]

<Wafer Charging and Boat Loading Step>

The plurality of the wafers including the wafer 200 are charged (transferred) into the boat 217 (wafer charging step). After the boat 217 is charged with the plurality of the wafers, the lower end opening of the manifold 226 is opened. 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 (boat loading step). With the boat 217 loaded, the seal cap 219 seals the lower end opening of the manifold 226 via the O-ring 220b.

[0053]

<Pressure Adjusting 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 are accommodated reaches a desired pressure (vacuum degree). In the pressure adjusting and temperature adjusting step, the inner pressure of the process chamber 201 is measured by the pressure sensor 245, and the APC valve 244 is feedback-controlled based on measured pressure information. The

heater 207 heats the process chamber 201 until the temperature of the wafer 200 in the process chamber 201 reaches a desired film-forming temperature. The state of electric conduction to the heater 207 is feedback-controlled based on the temperature information detected by a temperature sensor 263 such that the desired temperature distribution of the inner temperature of the process chamber 201 is obtained. The boat rotator 267 rotates the plurality of the wafers including the wafer 200 by rotating the boat 217. The vacuum pump 246 continuously vacuum-exhausts the inner atmosphere of the process chamber 201, the heater continuously heats the process chamber 201 and the boat rotator 267 continuously rotates the plurality of the wafers until at least the processing of the wafer 200 is completed.

[0054]

<Film-forming Step>

Thereafter, the film-forming step is performed by performing a step (A) and a step (B) sequentially.

[0055]

<Step (A)>

In the step (A), the HCDS gas is supplied to the wafer 200 in the process chamber 201. Specifically, the valve 330b is opened to supply the HCDS gas into the gas supply pipe 310b. A flow rate of the HCDS gas supplied into the gas supply pipe 310b is adjusted by the MFC 320b. The HCDS gas whose flow rate is adjusted is then supplied into the process chamber 201 through the nozzle 304b, and is exhausted through the exhaust port 230. In the step (A), the N_2 gas serving as the inert gas is supplied to the wafer 200 in the process chamber 201 through the nozzles 304a and 304c on both sides of the nozzle 304b. Specifically, the valves 330d and 330f are opened to supply the N_2 gas into the gas supply pipes 310a and 310c. A flow rate of the N_2 gas is adjusted by the MFCs 320d and 320f, the N_2 gas whose flow rate is adjusted is

supplied into the process chamber 201 through the nozzles 304a and 304c, and is exhausted through the exhaust port 230. That is, in the step (A), the HCDS gas and the N_2 gas are supplied to the wafer 200.

[0056]

For example, process conditions in the step (A) are exemplified as follows:

Supply flow rate of the HCDS gas: 0.001 slm (Standard Liters Per Minute) to 2 slm, preferably, 0.01 slm to 1 slm;

Supply flow rate of the N_2 gas (per gas supply pipe): 0.5 slm to 5 slm;

Gas supply time (a time duration of supplying the HCDS gas and the N_2 gas): 0.1 second to 120 seconds, preferably, 1 second to 60 seconds;

Process temperature: 250 °C to 800 °C, preferably, 400 °C to 700 °C; and

Process pressure: 1 Pa to 2,666 Pa, preferably, 67 Pa to 1,333 Pa.

[0057]

By supplying the HCDS gas and the N_2 gas to the wafer 200 under the above-described process conditions, for example, a silicon-containing layer containing chlorine (Cl) is formed as a first layer on an outermost surface of the wafer 200.

[0058]

After the first layer is formed on the wafer 200, the valve 330b is closed to stop the supply of the HCDS gas into the process chamber 201. Then, the inner atmosphere of the process chamber 201 is vacuum-exhausted to remove the substances such as the gas remaining in the process chamber 201. When the inner atmosphere of the process chamber 201 is vacuum-exhausted, with the valves 330d through 330f open, the N_2 gas is supplied into the process chamber 201 through the nozzles 304a, 304b and 304c. The N_2 gas supplied through the nozzles 304a, 304b and 304c serves as the purge gas. As a result, the inner atmosphere of the process chamber 201 is purged (purge step). In the purge step, for example, each flow rate of the N_2 gas supplied through each of the

nozzles 304a, 304b and 304c is set within a range from 0.1 slm to 2 slm. The other process conditions are the same as the process conditions in the step (A) described above.

[0059]

Instead of the HCDS gas, a chlorosilane source gas such as monochlorosilane (SiH_3Cl, abbreviated as MCS) gas, dichlorosilane (SiH_2Cl_2, abbreviated as DCS) gas, trichlorosilane ($SiHCl_3$, abbreviated as TCS) gas, tetrachlorosilane ($SiCl_4$, abbreviated as STC) gas, and octachlorotrisilane (Si_3Cl_8, abbreviated as OCTS) may be used as the source gas.

[0060]

Instead of the N_2 gas, for example, a rare gas such as argon (Ar) gas, helium (He) gas, neon (Ne) gas and xenon (Xe) gas may be used as the inert gas. The same also applies to the step (B) described later.

[0061]

<Step (B)>

After the step (A) is completed, the NH_3 gas is supplied to the wafer 200 in process chamber 201, that is, to the first layer formed on the wafer 200. Specifically, the valves 330a and 330c are opened to supply the NH_3 gas into the gas supply pipes 310a and 310c. A flow rate of the NH_3 gas supplied into each of the gas supply pipes 310a and 310c is adjusted by the MFCs 320a and 320c. The NH_3 gas whose flow rate is adjusted is then supplied into the process chamber 201 through the nozzles 304a and 304c, and is exhausted through the exhaust port 230. Thereby, the NH_3 gas is supplied to the wafer 200. In the step (B), by opening at least one among the valves 330d through 330f, the N_2 gas may be supplied into the process chamber 201 through at least one among the nozzles 304a, 304b and 304c.

[0062]

For example, the process conditions in the step (B) are exemplified as follows:

Supply flow rate of the NH_3 gas: 1 slm to 10 slm;

NH_3 gas supply time (a time duration of supplying the NH_3 gas): 0.1 second to 120 seconds, preferably, 1 second to 60 seconds;

Supply flow rate of the N_2 gas (per gas supply pipe): 0 slm to 2 slm; and

Process pressure: 1 Pa to 4,000 Pa, preferably, 1 Pa to 3,000 Pa.

The other process conditions are the same as the process conditions in the step (A) described above.

[0063]

By supplying the NH_3 gas to the wafer 200 under the above-described process conditions, at least a part of the first layer formed on the wafer 200 is nitrided (modified). By modifying the first layer, a second layer containing silicon and nitrogen, that is, an SiN layer is formed on the wafer 200. When the second layer is formed, impurities such as chlorine contained in the first layer may form a gas phase substance containing at least chlorine during a modifying reaction of the first layer by the NH_3 gas, and the gas phase substance is discharged from the process chamber 201. As a result, the second layer becomes a layer which contains a smaller amount of the impurities such as chlorine than the first layer.

[0064]

After the second layer is formed, the valves 330a and 330c are closed to stop the supply of the NH_3 gas into the process chamber 201. Then, the inner atmosphere of the process chamber 201 is vacuum-exhausted to remove the substances such as the gas remaining in the process chamber 201 according to the same process sequence and process conditions as those of the step (A).

[0065]

Instead of the NH_3 gas, for example, a hydrogen nitride-based gas such as diazene (N_2H_2) gas, hydrazine (N_2H_4) gas and N_3H_8 gas may be used as the reactant.

[0066]

<Performing a Predetermined Number of Times>

By performing a cycle wherein the step (A) and the step (B) are performed non-simultaneously in this order a predetermined number (n, n is an integer equal to or greater than 1) of times, an SiN film of a predetermined composition and a predetermined thickness is formed on the wafer 200. It is preferable that the cycle is performed a plurality of times. That is, the cycle is performed (repeated) until a total thickness of the SiN film formed by stacking the second layer by performing the cycle a plurality of times reaches the desired thickness under the condition that the second layer formed in each cycle is thinner than the desired thickness. In the present specification, the exemplary sequence of the film-forming process described above may be represented as follows:

(HCDS → NH_3) × n => SiN

In the following descriptions, the same also applies to other examples.

[0067]

<After-purge and Returning to Atmospheric Pressure Step>

After the film-forming step is completed, the N_2 gas serving as the purge gas is supplied into the process chamber 201 through each of the nozzles 304a, 304b and 304c, and then the N_2 gas supplied into the process chamber 201 is exhausted through the exhaust port 230. Thereby, the inner atmosphere of the process chamber 201 is purged with the N_2 gas, thus the gas remaining in the process chamber 201 or reaction by-products remaining in the process chamber 201 are removed from the process chamber 201 (after-purge). Thereafter, the inner atmosphere of the process chamber 201

is replaced with the inert gas (substitution by inert gas), and the inner pressure of the process chamber 201 is returned to the atmospheric pressure (returning to atmospheric pressure).

[0068]

<Boat Unloading and Wafer Discharging Step>

Thereafter, the seal cap 219 is lowered by the boat elevator 115 and the lower end opening of the manifold 226 is opened. The boat 217 with the plurality of processed wafers including the wafer 200 charged therein is unloaded out of the reaction tube 203 through the lower end opening of the manifold 226 (boat unloading). After the boat 217 is unloaded, the lower end opening of the manifold 226 is sealed by a shutter (not shown) through a seal such as an O-ring (shutter closing). Then, the plurality of the processed wafers including the wafer 200 are discharged from the boat 217 (wafer discharging).

[0069]

(3) Modified Examples

Subsequently, modified examples of the present embodiment will be described with reference to FIGS. 5 through 7. These modified examples may be arbitrarily combined. In addition, unless otherwise described, configurations of the modified examples are similar to the configuration of the embodiment described above.

[0070]

<First Modified Example>

As shown in FIG. 5, according to the present modified example, the three nozzles 304a, 304b and 304c are provided in the gas supply area 222, and are configured to supply the two or more types of the gas into the process chamber 201. However, a shape of a gas supply port of the nozzle 304b configured to supply the

source gas according to the present modified example is different from that of the nozzle 304b according to the embodiment described above.

[0071]

A vertically elongated slit-shaped opening 332b serving as the gas supply port configured to supply the gas is provided on the side surface of the nozzle 304b. An upper end of the opening 332b of the nozzle 304b is arranged lower than the lowermost dummy wafer among the dummy wafers 200b supported in the upper dummy wafer support region. In addition, a lower end of the opening 332b of the nozzle 304b is arranged higher than the uppermost dummy wafer among the dummy wafers 200b supported in the lower dummy wafer support region. That is, in the nozzle 304b, the opening 332b is provided in the product wafer support region, but is not provided in the upper dummy wafer support region and the lower dummy wafer support region. With such a configuration, when the source gas is supplied in the step (A) of the film-forming step described above, the source gas is supplied to the wafer 200 in the process chamber 201 through the opening 332b of the nozzle 304b and the inert gas is supplied through the gas supply holes 232a and the gas supply holes 232c of the nozzles 304a and 304c arranged on both sides of the nozzle 304b.

[0072]

<Second Modified Example>

As shown in FIG. 6, according to the present modified example, three nozzles 404a, 304b and 404c are provided in the gas supply area 222, and are configured to supply the two or more types of the gas into the process chamber 201. However, shapes of the nozzle 404a and the nozzle 404c arranged on both sides of the nozzle 304b configured to supply the source gas according to the present modified example are different from those of the nozzle 304a and the nozzle 304c according to the first modified example described above.

[0073]

The nozzles 404a, 304b and 404c are provided in the gas supply area 222 from the lower portion toward the upper portion along the longitudinal direction of the gas supply area 222 (vertical direction). The nozzle 304b extends in the vertical direction along the boat 217 accommodated in the process chamber 201, and is configured as an I-shaped long nozzle of a tube shape (pipe shape). Each of the nozzle 404a and the nozzle 404c is a multi-hole nozzle (porous nozzle), extends in the vertical direction along the boat 217 accommodated in the process chamber 201, and is configured as a U-shaped long nozzle of a tube shape (pipe shape).

[0074]

The nozzle 404a is constituted by: an ascending pipe 404a-1 connected to the gas supply pipe 310a such that the fluid can flow from the gas supply sources 360a and 360d to a lower end of the ascending pipe 404a-1 through the gas supply pipe 310a; and a descending pipe 404a-2 connected to an upper end of the ascending pipe 404a-1 such that the fluid can flow and provided substantially parallel to the ascending pipe 404a-1.

[0075]

The nozzle 304b is connected to the gas supply pipe 310b such that the fluid can flow from the gas supply sources 360b and 360e to the lower end of the nozzle 304b through the gas supply pipe 310b.

[0076]

The nozzle 404c is constituted by: an ascending pipe 404c-1 connected to the gas supply pipe 310c such that the fluid can flow from the gas supply sources 360c and 360f to a lower end of the ascending pipe 404c-1 through the gas supply pipe 310c; and a descending pipe 404c-2 connected to an upper end of the ascending pipe 404c-1 such that the fluid can flow and provided substantially parallel to the ascending pipe 404c-1.

[0077]

The gas supply holes 232a and the gas supply holes 232c are provided in the upper dummy wafer support region and the lower dummy wafer support region of the ascending pipes 404a-1 and 404c-1 and in the upper dummy wafer support region, the product wafer support region and the lower dummy wafer support region of the descending pipes 404a-2 and 404c-2 on side surfaces of the nozzles 304a and 304c, respectively. That is, the number of the gas supply holes 232a and the gas supply holes 232c in the dummy wafer region of the nozzles 404a and 404c configured to supply the inert gas may be more than the number of the gas supply holes 232a and the gas supply holes 232c of the nozzles 304a and 304c in the embodiment and the first modified example described above. As a result, it is possible to further lower a concentration of the silicon source in the dummy wafer support region, and it is also possible to easily control the uniformity of the film thickness on the surface of the product wafer and the uniformity of the film thickness among the product wafers.

[0078]

Upper ends of uppermost gas supply holes among the gas supply holes 232a and the gas supply holes 232c of the nozzles 404a and 404c are arranged corresponding to the uppermost dummy wafer among the dummy wafers 200b supported in the upper dummy wafer support region. In addition, lower ends of lowermost gas supply holes among the gas supply holes 232a and the gas supply holes 232c of the nozzles 404a and 404c of the nozzles 404a and 404c are arranged corresponding to the lowermost dummy wafer among the dummy wafers 200b supported in the lower dummy wafer support region. With such a configuration, when the source gas is supplied in the step (A) of the film-forming step described above, the source gas is supplied to the wafer 200 in the process chamber 201 through the opening 332b of the nozzle 304b and the inert gas is supplied through the gas supply holes 232a and the gas supply holes 232c of the nozzles 404a and 404c arranged on both sides of the nozzle 304b.

[0079]

That is, the nozzles 404a and 404c are configured such that a substantial opening area which is obtained by averaging along the longitudinal direction the opening areas of the gas supply holes 232a and 232c arranged in the upper and the lower dummy wafer support region is greater than another substantial opening area which is obtained by averaging along the longitudinal direction the opening areas of the gas supply holes 232a and 232c arranged in the product wafer support region.

[0080]

In addition, the nozzles 404a and 404c are configured such that an average opening width of each of the gas supply holes 232a and the gas supply holes 232c averaged in a nozzle longitudinal direction is 1% or less of a square root of a cross-sectional area of a flow path of each of the nozzles 404a and 404c. According to the present modified example, the average opening width averaged in the nozzle longitudinal direction may also refer to an opening width of a continuous slit in the longitudinal direction whose conductance is equal to a conductance per unit length in the longitudinal direction of the gas supply holes 232a or the gas supply holes 232c. In addition, the nozzle 304b is configured such that an opening width of the opening 332b of the nozzle 304b is 3% or more of a square root of a cross-sectional area of a flow path of the nozzle 304b. Instead of one continuous opening from the upper end thereof to the lower end thereof, the opening 332b may be configured as a plurality of slits extending intermittently in the vertical direction and bridged on both sides thereof in order to increase the strength thereof.

[0081]

<Third Modified Example>

As shown in FIG. 7, according to the present modified example, the three nozzles 304a, 304b and 404c are provided in the gas supply area 222, and are

configured to supply the two or more types of the gas into the process chamber 201. However, the shape of the nozzle 404c provided at the side of the nozzle 304b configured to supply the source gas according to the present modified example is different from that of the nozzle 304c according to the first modified example described above.

[0082]

The nozzles 304a, 304b and 404c are provided in the gas supply area 222 from the lower portion toward the upper portion along the longitudinal direction of the gas supply area 222 (vertical direction). Each of the nozzles 304a and 304b extends in the vertical direction along the boat 217 accommodated in the process chamber 201, and is configured as an I-shaped long nozzle of a tube shape (pipe shape). The nozzle 404c extends in the vertical direction along the boat 217 accommodated in the process chamber 201, and is configured as a U-shaped long nozzle of a tube shape (pipe shape).

[0083]

The nozzle 304a is connected to the gas supply pipe 310a such that the fluid can flow from the gas supply sources 360a and 360d to the lower end of the nozzle 304a through the gas supply pipe 310a.

[0084]

The nozzle 304b is connected to the gas supply pipe 310b such that the fluid can flow from the gas supply sources 360b and 360e to the lower end of the nozzle 304b through the gas supply pipe 310b.

[0085]

The nozzle 404c is constituted by: the ascending pipe 404c-1 connected to the gas supply pipe 310c such that the fluid can flow from the gas supply sources 360c and 360f to the lower end of the ascending pipe 404c-1 through the gas supply pipe 310c; and the descending pipe 404c-2 connected to the upper end of the ascending pipe

404c-1 such that the fluid can flow and provided substantially parallel to the ascending pipe 404c-1.

[0086]

The gas supply holes 232c are provided in the product wafer support region, the upper dummy wafer support region and the lower dummy wafer support region on a side surface of the descending pipe 404c-2 of the nozzle 404c. The gas supply holes 232c are not provided in the ascending pipe 404c-1 of the nozzle 404c.

[0087]

The upper end of the uppermost gas supply hole among the gas supply holes 232a of the nozzle 304a and the upper end of the uppermost gas supply hole among the gas supply holes 232c of the descending pipe 404c-2 of the nozzle 404c are arranged corresponding to the uppermost dummy wafer among the dummy wafers including the dummy wafer 200b supported in the upper dummy wafer support region. In addition, the lower end of the lowermost gas supply hole among the gas supply holes 232a of the nozzle 304a and the lower end of the lowermost gas supply hole among the gas supply holes 232c of the descending pipe 404c-2 of the nozzle 404c are arranged corresponding to the lowermost dummy wafer among the dummy wafers including the dummy wafer 200b supported in the lower dummy wafer support region. With such a configuration, when the source gas is supplied in the step (A) of the film-forming step described above, the source gas is supplied to the wafer 200 in the process chamber 201 through the opening 332b of the nozzle 304b and the inert gas is supplied through the gas supply holes 232a and the gas supply holes 232c of the nozzles 304a and 404c arranged on both sides of the nozzle 304b.

[0088]

By supplying the inert gas (purge gas) using the U-shaped (return shape) nozzle 404c according to the present modified example, it is possible to improve the quality of

the film formed on the wafer 200. For example, the purge gas (N_2 gas), which is effective in improving the thickness uniformity of the film, is often supplied at a large flow rate of 2 slm to 10 slm. The purge gas is supplied to wafers provided in the lower portion of the boat 217 among the plurality of the wafers through the I-shaped nozzle before the purge gas is sufficiently warmed up. As a result, a temperature of the purge gas may not be uniform from the lower portion to an upper portion of the boat 217. However, by using the U-shaped nozzle 404c, it is possible to sufficiently warm the purge gas before being supplied to the plurality of the wafers including the wafer 200. As the temperature of the purge gas increases, a diffusion rate of gas molecules also increases, and it is expected that it is possible to shorten an alternate supply interval of the source gas while maintaining the quality of the film. In addition, a temperature at which the NH_3 gas becomes a radical or a precursor is higher than a temperature at which the HCDS gas becomes a radical or a precursor. That is, it is demanded for the NH_3 gas to become the precursor at a predetermined temperature or higher, and it is preferable to maintain the NH_3 gas in the nozzle for a sufficient time when lowering the process temperature to the predetermined temperature. Preferably, by increasing a volume of the nozzle by using the U-shaped nozzle 404c, it is possible to apply the nozzle 404c to supply the reactive gas which is difficult to be decomposed.

[0089]

<Other Embodiments>

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

[0090]

For example, while the above-described embodiment and the modified examples are described by way of an example in which the nitriding gas such as the NH_3 gas is supplied through the two nozzles 304a and 304c, the above-described technique is not limited thereto. For example, the nitriding gas may be supplied through at least one among the nozzle 304a and the nozzle 304c.

[0091]

For example, while the above-described embodiment and the modified examples are described by way of an example in which the gas supply holes 232b are provided only in the product wafer support region on the side surface of the nozzle 304b configured to supply the source gas, the above-described technique is not limited thereto. For example, the above-described technique may be preferably applied when the total opening area of the gas supply holes 232b or the opening 332b provided in the dummy wafer support region on the side surface of the nozzle 304b is smaller than the total opening area of the gas supply holes 232a and the gas supply holes 232c provided on the side surfaces of the nozzles 304a and 304c configured to supply the inert gas and arranged on both sides of the nozzle 304b.

[0092]

For example, while the above-described embodiment and the modified examples are described by way of an example in which the gas supply holes 232b are provided only in the product wafer support region on the side surface of the nozzle 304b configured to supply the source gas, the above-described technique is not limited thereto. For example, the above-described technique may be preferably applied when the total opening area of the gas supply holes 232a and the gas supply holes 232c provided on the side surfaces of the nozzles 304a and 304c configured to supply the inert gas and arranged on both sides of the nozzle 304b is larger than the total opening area of the gas

supply holes 232b or the opening 332b provided in the dummy wafer support region on the side surface of the nozzle 304b.

[0093]

For example, while the above-described embodiment and the modified examples are described by way of an example in which the film containing silicon as the main element is formed on the substrate (wafer), the above-described technique is not limited thereto. For example, the above-described technique may be preferably applied to form on the substrate a film containing a metalloid element such as germanium (Ge) and boron (B) as a main element other than silicon. In addition, the above-described technique may be preferably applied to form on the substrate a film containing a metal element such as titanium (Ti), zirconium (Zr), hafnium (Hf), niobium (Nb), tantalum (Ta), molybdenum (Mo), tungsten (W), yttrium (Y), lanthanum (La), strontium (Sr) and aluminum (Al) as a main element.

[0094]

For example, the above-described technique may be applied to form on the substrate films such as a titanium nitride film (TiN film), a titanium oxynitride film (TiON film), a titanium aluminum carbonitride film (TiAlCN film), a titanium aluminum carbide film (TiAlC film), a titanium carbonitride film (TiCN film) and a titanium oxide film (TiO film). For example, gases such as titanium tetrachloride ($TiCl_4$) gas and trimethylaluminum ($Al(CH_3)_3$, abbreviated as TMA) gas may be used when forming the films described above.

[0095]

$(TiCl_4 \rightarrow NH_3) \times n \Rightarrow TiN$

$(TiCl_4 \rightarrow NH_3 \rightarrow O_2) \times n \Rightarrow TiON$

$(TiCl_4 \rightarrow TMA \rightarrow NH_3) \times n \Rightarrow TiAlCN$

$(TiCl_4 \rightarrow TMA) \times n \Rightarrow TiAlC$

$(TiCl_4 \rightarrow TEA) \times n \Rightarrow TiCN$

$(TiCl_4 \rightarrow H_2O) \times n \Rightarrow TiO$

[0096]

The recipe used for the substrate processing may be separately prepared depending on the contents of the substrate processing, and stored in the memory 121c through an electrical telecommunication line or the external memory 123. When the substrate processing is started, the CPU 121a may select a proper recipe among a plurality of recipes stored in the memory 121c, depending on the contents of the substrate processing. Thus, it is possible to form plural kinds of films of various composition ratios, qualities and thicknesses by only a single substrate processing apparatus in a universal and highly reproducible manner. Furthermore, it is possible to reduce the burden of an operator, and to start the substrate processing promptly without an operation mistake.

[0097]

The above-described recipes are not limited to newly created recipes. For example, an existing recipe which is already installed in the substrate processing apparatus may be changed to a new recipe. When a recipe is to be changed, the recipe may be installed in the substrate processing apparatus through an electrical communication line or a recording medium in which the recipe is written. The input/output device 122 installed in the existing substrate processing apparatus may be operated to directly change the existing recipe which is already installed in the substrate processing apparatus to the new recipe.

[0098]

The above-described embodiment and the modified examples may be appropriately combined. The process sequences and the process conditions of the

combinations may be substantially the same as those of the above-described embodiment.

[0099]

Films such as the SiN film formed in accordance with the above-described embodiment or the modified examples may be widely used, for example, as an insulating film, a spacer film, a mask film, a charge storage film and a stress control film. In recent years, as the semiconductor device is miniaturized, a thickness uniformity of the film formed on the surface of the wafer is more strictly demanded. The above-described technique capable of forming a film of a flat distribution on a patterned substrate with a high-density pattern formed thereon is very useful as a technique for responding to this demand.

[0100]

<Examples>

Hereinafter, simulation results and evaluation results that support the effects obtained in the embodiment and the modified examples described above will be described with reference to FIGS. 8 through 12.

[0101]

According to a comparative example, the gases are supplied to the plurality of the wafers including the wafer 200 stacked in a multistage manner on the boat 217 by using the three nozzles 304a, 404b and 404c shown in FIG. 8(A). Specifically, each of the flow rates of the N_2 gas supplied through the nozzle 304a and the nozzle 404c is set to 100 sccm, and the flow rate of the HCDS gas supplied through the nozzle 404b are set to 480 sccm. An opening 432b configured to supply the HCDS gas are provided on the side surface of the nozzle 404b in the upper dummy wafer support region, the product wafer support region and the lower dummy wafer support region.

[0102]

According to an example of the present embodiment, the gases are supplied to the plurality of the wafers including the wafer 200 stacked in a multistage manner on the boat 217 by using the three nozzles 304a, 304b and 404c shown in FIG. 8(B) according to the third modified example described above. Specifically, each of the flow rates of the N_2 gas supplied through the nozzle 304a and the nozzle 404c are set to 500 sccm, and the flow rate of the HCDS gas supplied through the nozzle 304b are set to 480 sccm.

[0103]

FIG. 9(A) schematically illustrates the simulation result showing a concentration distribution of the silicon source in the process furnace 202 when the nozzles according to the comparative example shown in FIG. 8(A) are used, and FIG. 9(B) schematically illustrates the thickness distribution of the film on the surface of the product wafer and the thickness distribution of the film among the product wafers including the product wafer shown in FIG. 9(A). FIG. 10(A) schematically illustrates the simulation result showing a concentration distribution of the silicon source in the process furnace 202 when the nozzles according to the example of the embodiment shown in FIG. 8(B) are used, and FIG. 10(B) schematically illustrates the thickness distribution of the film on the surface of the product wafer and the thickness distribution of the film among the plurality of the product wafers including the product wafer shown in FIG. 10(A). The vertical axis shown in FIGS. 9(B) and 10(B) represents a partial pressure [Pa] of the silicon source. The horizontal axis shown in FIGS. 9(B) and 10(B) represents a wafer number (wafer serial number) of the product wafers placed on the boat 217.

[0104]

As shown in FIG. 9(A), when the nozzles according to the comparative example are used, the opening 432b is also provided in the upper dummy wafer support

region and the lower dummy wafer support region on the side surface of the nozzle 404b configured to supply the source gas. Therefore, the source gas is uniformly supplied from the top to the bottom of the boat 217. However, since the dummy wafer supported in the dummy wafer support region is a flat wafer and the product wafer on which the pattern is formed is a structural wafer whose surface area is large, the consumption of the source gas is different between the dummy wafer and the product wafer. Therefore, the concentration (partial pressure) of the silicon source in the process chamber 201 is different among the upper dummy wafer support region, the lower dummy wafer support region and the product wafer support region. In the upper dummy wafer support region and the lower dummy wafer support region, the concentration of the silicon source increases because the excess gas is large. In the product wafer support region, the concentration of the silicon source decreases. When a concentration difference of the silicon source occurs in the process chamber 201, the concentration difference also occurs even in the product wafer support region due to a concentration diffusion. Specifically, the concentration (partial pressure) of the silicon source in a region in the product wafer support region in the vicinity of the upper dummy wafer support region or the lower dummy wafer support region may be different from the concentration (partial pressure) of the silicon source in a region far from the upper dummy wafer support region or the lower dummy wafer support region. Therefore, the uniformity of the film formed on the product wafer may deteriorate.

[0105]

In addition, as shown in FIG. 9(B), when the nozzles according to the comparative example are used, the partial pressure of the silicon source supplied around the edge within the surface of the wafer is different from the partial pressure of the silicon source supplied to the center within the surface of the wafer. On the other hand,

as shown in FIG. 10(B), it is confirmed that, when the nozzles according to the example of the embodiment are used, the uniformity on the surface of the wafer is desirable.

[0106]

In addition, as shown in FIG. 9(B), when the nozzles according to the comparative example are used, the partial pressure of the silicon source supplied to the plurality of the wafers stacked in the height direction of the boat 217 varies depending on the position of each of the plurality of the wafers. On the other hand, as shown in FIG. 10(B), it is confirmed that, when the nozzles according to the example of the embodiment are used, the uniformity among the plurality of the wafers is desirable. That is, according to the example of the embodiment, it is possible to improve a uniformity of the concentration of the silicon source supplied to the product wafer.

[0107]

That is, when the nozzles according to the example of the embodiment are used, it is possible to uniformize the concentration of the silicon source in the height direction of the plurality of the wafers stacked in the boat 217 as compared with the case where the nozzles according to the comparative example are used. In particular, it is confirmed that it is possible to reduce the concentration of the silicon source on the upper portion and the lower portion of the boat 217 and to improve the uniformity among the plurality of the wafers.

[0108]

FIG. 11 schematically illustrates comparison results of thickness distributions of the SiN film on the surface of the product wafer when the SiN film is formed on the product wafer using the nozzles according to the comparative example and the nozzles according to the example of the embodiment. FIG. 12 schematically illustrates comparison results of thickness distributions of the SiN film among the plurality of the product wafers when the SiN film is formed on the plurality of the product wafers using

the nozzles according to the comparative example and the nozzles according to the example of the embodiment. The vertical axis shown in FIG. 11 represents a wafer position. The horizontal axis shown in FIG. 11 represents the uniformity [%] on the surface of the product wafer. The vertical axis shown in FIG. 12 represents the wafer position. The horizontal axis shown in FIG. 12 represents the thickness [Å] of the SiN film formed on the product wafer.

[0109]

As shown in FIG. 11, the uniformity of the film (SiN film) on the surface of the product wafer is about 4.5% at a center portion ("CENTER" in FIG. 11) of the boat 217, about 7.5% at the lower portion ("BOTTOM" in FIG. 11) of the boat 217, and about 9.2% at the upper portion ("TOP" in FIG. 11) of the boat 217 when the film is formed using the nozzles according to the comparative example. That is, the uniformity of the film on the surface of the product wafer varies greatly depending on the height position of the product wafer. On the other hand, the uniformity of the film on the surface of the product wafer is about 4% when the film is formed using the nozzles according to the example of the embodiment. That is, the uniformity of the film on the surface of the product wafer shows almost no difference along the height direction of the boat 217.

[0110]

In addition, as shown in FIG. 12, the uniformity of the film among the plurality of the wafers is about 7% when the film is formed using the nozzles according to the comparative example. On the other hand, it is confirmed that, when the film is formed using the nozzles according to the example of the embodiment, the uniformity of the film among the plurality of the wafers is about 2%. That is, the uniformity of the film among the plurality of the wafers is also desirable.

[0111]

That is, as compared with the case when the nozzles according to the comparative example are used, the uniformity of the film thickness among the product wafers stacked in the boat 217 is desirable from the lower portion to the upper portion in the height direction of the boat 217 when the nozzles according to the example of the embodiment are used, and it is possible to obtain a uniform film thickness among the product wafers stacked in a multistage manner in the boat 217 from the lower portion to the upper portion of the boat 217 when the nozzles according to the example of the embodiment are used.

[Description of Reference Numerals]

[0112]

200: wafer (substrate)

217: boat (substrate retainer)

304a, 404a: nozzle (first gas supplier)

304b: nozzle (second gas supplier)

304c, 404c: nozzle (third gas supplier)

232a, 232b, 232c: gas supply holes

332b: opening

[CLAIMS]

[Claim 1]

A substrate processing apparatus comprising:

a substrate retainer configured to accommodate a plurality of wafers in a horizontal orientation and in a multistage manner, and comprising:

a product wafer support region where a plurality of product wafers are supported;

an upper wafer support region provided above the product wafer support region and capable of supporting upper wafers among the plurality of wafers; and

a lower wafer support region provided below the product wafer support region and capable of supporting lower wafers among the plurality of wafers;

a process chamber in which the substrate retainer is accommodated;

a first gas supplier, a second gas supplier and a third gas supplier configured to supply gases into the process chamber; and

an exhaust system configured to exhaust an inner atmosphere of the process chamber,

wherein the first gas supplier comprises a first injector extending vertically along a stacking direction of the plurality of wafers and provided with a plurality of first supply holes capable of supplying a dilution gas therethrough at least to the upper wafer support region,

wherein the second gas supplier comprises a second injector provided with a plurality of second supply holes capable of supplying a source gas therethrough to the product wafer support region,

wherein the third gas supplier comprises a third injector extending vertically along the stacking direction of the plurality of wafers and provided with a plurality of

third supply holes capable of supplying the dilution gas therethrough at least to the lower wafer support region, and

wherein the first injector, the second injector and the third injector are provided in a gas supply area formed at a location in the process chamber facing the exhaust system, and the second injector is interposed between the first injector and the third injector.

[Claim 2]

The substrate processing apparatus of claim 1, wherein a pattern is formed on each of the plurality of product wafers to increase a surface area of each of the product wafers, and

wherein the dilution gas supplied from the first gas supplier and the third gas supplier reduces a difference in a concentration of the source gas between: (i) a portion of the product wafer support region located in vicinity of the upper wafer support region or the lower wafer support region; and (ii) another portion of the product wafer support region located far away from the upper wafer support region and the lower wafer support region.

[Claim 3]

The substrate processing apparatus of claim 2, wherein a plurality of dummy wafers are accommodated in each of the upper wafer support region and the lower wafer support region.

[Claim 4]

The substrate processing apparatus of claim 2, wherein the plurality of first supply holes, the plurality of second supply holes and the plurality of third supply holes are open toward centers of wafers corresponding thereto.

[Claim 5]

The substrate processing apparatus of claim 1, further comprising:

a gas exhaust area facing the second gas supplier and extending vertically along the stacking direction of the plurality of wafers; and

an exhaust port in communication with a lower portion of the gas exhaust area,

wherein the second gas supplier is interposed between the first gas supplier and the third gas supplier and extends vertically along the stacking direction of the plurality of wafers, and the plurality of second supply holes are provided at a side surface of the second injector to solely face the plurality of product wafers in the product wafer support region.

[Claim 6]

The substrate processing apparatus of claim 1, wherein at least one of the first injector or the third injector comprises: an ascending pipe whose lower end is connected to an inert gas supplier so as to enable a fluidic flow therebetween; and a descending pipe connected to an upper end of the ascending pipe so as to enable the fluidic flow therebetween and installed substantially parallel to the ascending pipe, and

wherein at least one of the plurality of first supply holes or the plurality of third supply holes are provided at the descending pipe.

[Claim 7]

The substrate processing apparatus of claim 1, wherein at least one of the plurality of first supply holes or the plurality of third supply holes are arranged such that an opening area of the first supply holes averaged out along a longitudinal direction of the upper wafer support region or the third supply holes averaged out along a longitudinal direction of the lower wafer support region is greater than an opening area of the plurality of second supply holes averaged out along a longitudinal direction of the product wafer support region.

[Claim 8]

The substrate processing apparatus of claim 6, wherein at least one of the plurality of first supply holes or the plurality of third supply holes are arranged at both of the ascending pipe and the descending pipe in the upper wafer support region or the lower wafer support region, and are arranged at the descending pipe in the product wafer support region without being arranged at the ascending pipe in the product wafer support region.

[Claim 9]

The substrate processing apparatus of claim 1 or 2, wherein an upper end of an uppermost supply hole among the plurality of second supply holes of the second gas supplier is located lower than a lowermost wafer among the upper wafers in the upper wafer support region, and a lower end of a lowermost supply hole among the plurality of second supply holes is located higher than an uppermost wafer among the lower wafers in the lower wafer support region.

[Claim 10]

The substrate processing apparatus of claim 1 or 2, further comprising:

a first valve capable of opening and closing a communication between a dilution gas supply source and the first injector;

a second valve capable of opening and closing a communication between a source gas supply source and the second injector; and

a third valve capable of opening and closing a communication between a reactant gas supply source and the first injector,

wherein the first gas supplier supplies the dilution gas while the second gas supplier supplies the source gas, and

wherein the first gas supplier supplies a reactant gas while the second gas supplier does not supply the source gas.

[Claim 11]

The substrate processing apparatus of claim 1, wherein each of the first injector of the first gas supplier and the third injector of the third gas supplier comprises a plurality of openings whose opening width averaged out along a longitudinal direction of each of the upper wafer support region and the lower wafer support region is 1% or less of a square root of a cross-sectional area of a flow path therein, and the second injector of the second gas supplier comprises a plurality of openings whose opening width averaged out along a longitudinal direction of the product wafer support region is 3% or more of a square root of a cross-sectional area of a flow path therein.

[Claim 12]

The substrate processing apparatus of claim 1, wherein the process chamber is constituted by a cylinder whose inner diameter is 104 % to 108 % of a maximum diameter of the plurality of product wafers accommodatable in the process chamber, and the first injector of the first gas supplier, the second injector of the second gas supplier

and the third injector of the third gas supplier are provided in a supply area formed by a part of a side portion of the process chamber protruding outward while separated from one another.

[Claim 13]

A substrate processing method, comprising:

(a) accommodating, in a substrate retainer, a plurality of wafers in a horizontal orientation and in a multistage manner with the same interval therebetween, wherein the substrate retainer comprises: a product wafer support region where a plurality of product wafers, each having a pattern formed thereon, are supported; an upper wafer support region which is provided above the product wafer support region and where upper wafers among the plurality of wafers are supported; and a lower wafer support region which is provided below the product wafer support region and where lower wafers among the plurality of wafers are supported;

(b) loading the substrate retainer where the plurality of wafers are accommodated into a process chamber where a first gas supplier, a second gas supplier and a third gas supplier are provided, wherein each of the first gas supplier, the second gas supplier and the third gas supplier is configured to supply a gas into the process chamber;

(c) supplying a source gas to the product wafer support region by a second injector of the second gas supplier through a plurality of second supply holes;

(d) supplying a dilution gas to the upper wafer support region by a first injector of the first gas supplier through a plurality of first supply holes, wherein the first injector extends vertically along a stacking direction of the plurality of wafers and the plurality of first supply holes are provided to correspond to the upper substrates; and

(e) supplying the dilution gas to the lower wafer support region by a third injector of the third gas supplier through a plurality of third supply holes, wherein the third injector extends vertically along the stacking direction of the plurality of wafers and the plurality of third supply holes are provided to correspond to the lower substrates.

[Claim 14]

A method of manufacturing a semiconductor device, comprising:

(a) accommodating, in a substrate retainer, a plurality of wafers in a horizontal orientation and in a multistage manner with the same interval therebetween, wherein the substrate retainer comprises: a product wafer support region where a plurality of product wafers, each having a pattern formed thereon, are supported; an upper wafer support region which is provided above the product wafer support region and where upper wafers among the plurality of wafers are supported; and a lower wafer support region which is provided below the product wafer support region and where lower wafers among the plurality of wafers are supported;

(b) loading the substrate retainer where the plurality of wafers are accommodated into a process chamber where a first gas supplier, a second gas supplier and a third gas supplier are provided, wherein each of the first gas supplier, the second gas supplier and the third gas supplier is configured to supply a gas into the process chamber;

(c) supplying a source gas to the product wafer support region by a second injector of the second gas supplier through a plurality of second supply holes;

(d) supplying a dilution gas to the upper wafer support region by a first injector of the first gas supplier through a plurality of first supply holes, wherein the first

injector extends vertically along a stacking direction of the plurality of wafers and the plurality of first supply holes are provided to correspond to the upper substrates; and

(e) supplying the dilution gas to the lower wafer support region by a third injector of the third gas supplier through a plurality of third supply holes, wherein the third injector extends vertically along the stacking direction of the plurality of wafers and the plurality of third supply holes are provided to correspond to the lower substrates.

[Claim 15]

The substrate processing apparatus of claim 13, wherein in (a), each of the upper wafer support region and the lower wafer support region accommodates a plurality of dummy wafers while the product wafer support region accommodates the plurality of product wafers, and

wherein, in (d) or in (e) or in both of (d) and (e), the dilution gas supplied from at least one of the plurality of first supply holes or the plurality of third supply holes is supplied so as to reduce a difference in a concentration of the source gas between: (i) a portion of the product wafer support region located in vicinity of the upper wafer support region or the lower wafer support region; and (ii) another portion of the product wafer support region located far away from the upper wafer support region and the lower wafer support region.

[Claim 16]

A program related to a substrate processing apparatus, wherein the program causes, by a computer, the substrate processing apparatus to perform:

(a) accommodating, in a substrate retainer, a plurality of wafers in a horizontal orientation and in a multistage manner with the same interval therebetween, wherein the

substrate retainer comprises: a product wafer support region where a plurality of product wafers, each having a pattern formed thereon, are supported; an upper wafer support region which is provided above the product wafer support region and where upper wafers among the plurality of wafers are supported; and a lower wafer support region which is provided below the product wafer support region and where lower wafers among the plurality of wafers are supported;

(b) loading the substrate retainer where the plurality of wafers are accommodated into a process chamber where a first gas supplier, a second gas supplier and a third gas supplier are provided, wherein each of the first gas supplier, the second gas supplier and the third gas supplier is configured to supply a gas into the process chamber;

(c) supplying a source gas to the product wafer support region by a second injector of the second gas supplier through a plurality of second supply holes;

(d) supplying a dilution gas to the upper wafer support region by a first injector of the first gas supplier through a plurality of first supply holes, wherein the first injector extends vertically along a stacking direction of the plurality of wafers and the plurality of first supply holes are provided to correspond to the upper substrates; and

(e) supplying the dilution gas to the lower wafer support region by a third injector of the third gas supplier through a plurality of third supply holes, wherein the third injector extends vertically along the stacking direction of the plurality of wafers and the plurality of third supply holes are provided to correspond to the lower substrates.