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(54) **SUBSTRATE PROCESSING APPARATUS AND PRODUCING METHOD OF SEMICONDUCTOR DEVICE**

(76) Inventors: **Hironobu MIYA**, Toyama-shi (JP); **Taketoshi Sato**, Toyama-shi (JP); **Norikazu Mizuno**, Toyama-shi (JP); **Masanori Sakai**, Takaoka-shi (JP); **Takaaki Noda**, Toyama-shi (JP)

Correspondence Address:
BIRCH STEWART KOLASCH & BIRCH
PO BOX 747
FALLS CHURCH, VA 22040-0747 (US)

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(57) **ABSTRACT**

Disclosed is a substrate processing apparatus, comprising a processing chamber, a holder to hold at least a plurality of product substrates, a heating member, a supplying member to alternately supply at least a first reactant and a second reactant, and a control unit, wherein the control unit executes forming thin films on the substrates by supplying the first reactant, removing a surplus of the first reactant after the first reactant has been adsorbed on the product substrates, subsequently supplying the second reactant, to cause the second reactant to react with the first reactant adsorbed on the substrates, and executes the forming the thin films in a state where a number of the product substrates is insufficient when a number of the product substrates is less than a maximum number of the product substrates which can be held by the holder.

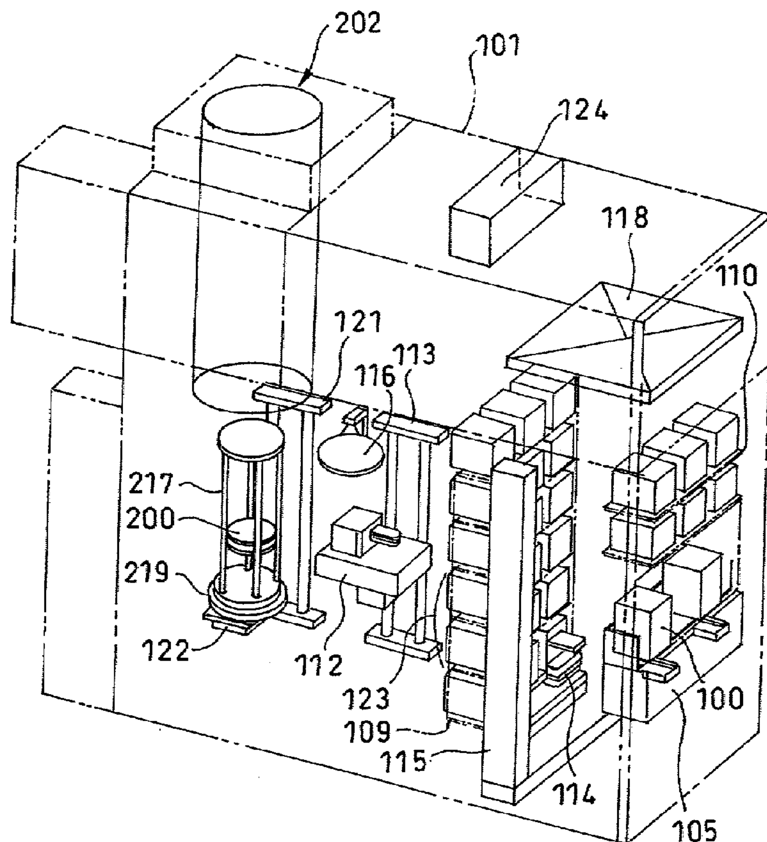


FIG.1

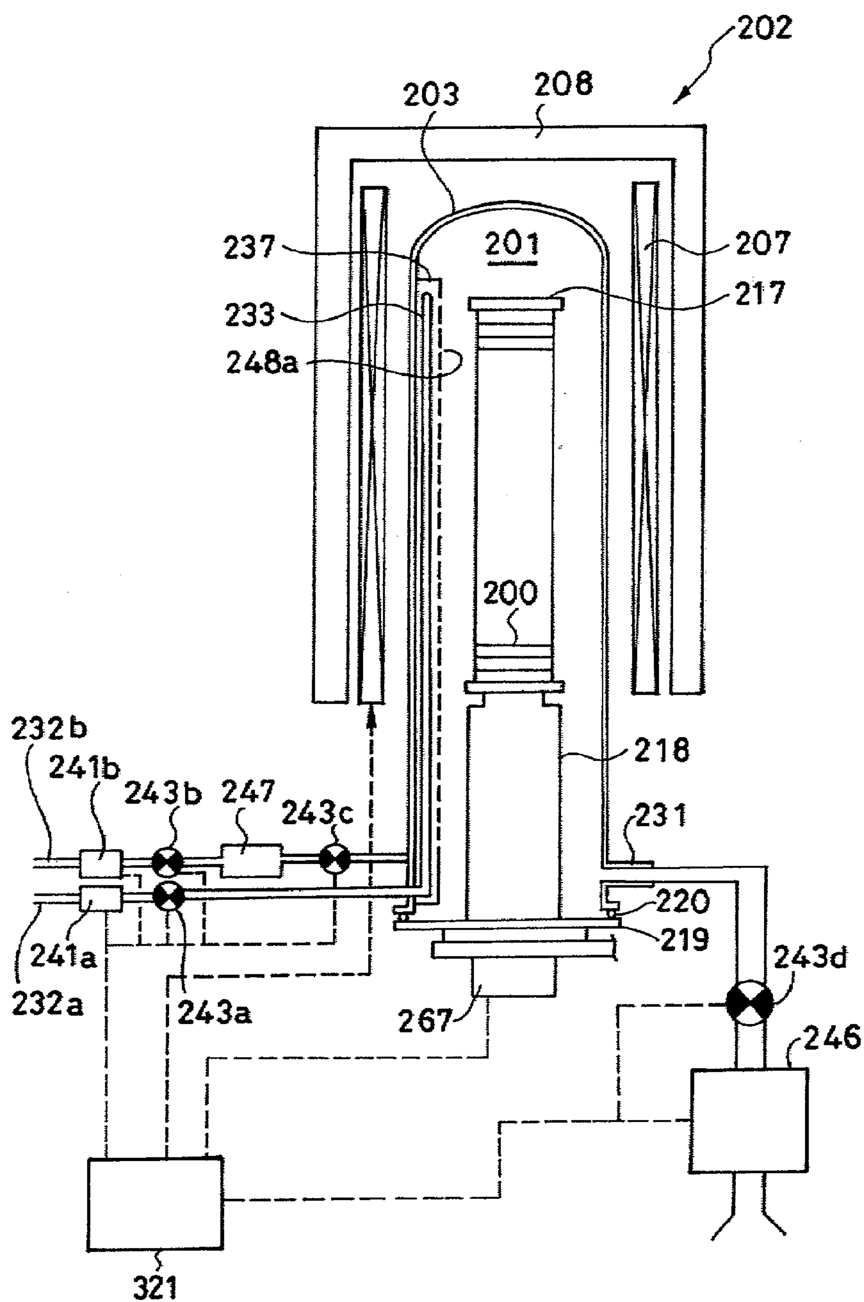


FIG.2

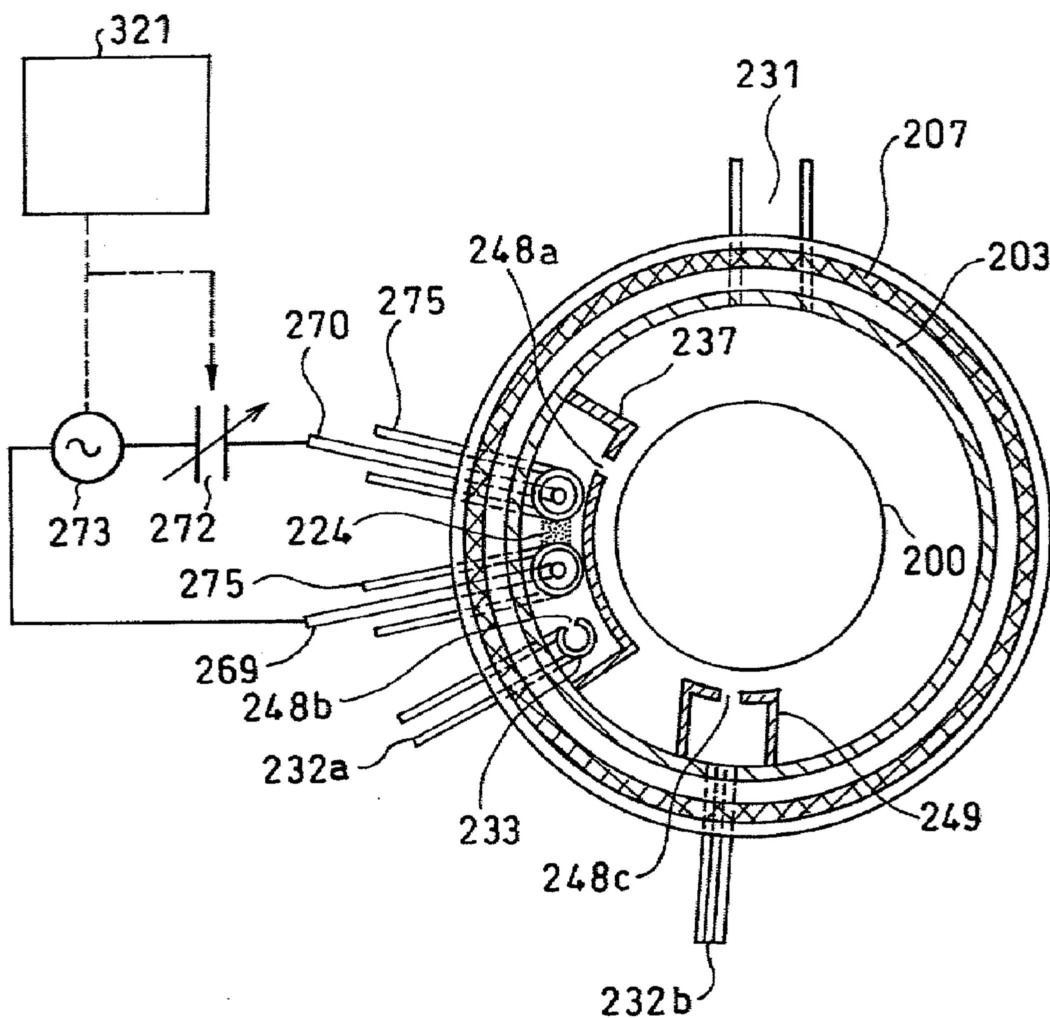


FIG.3

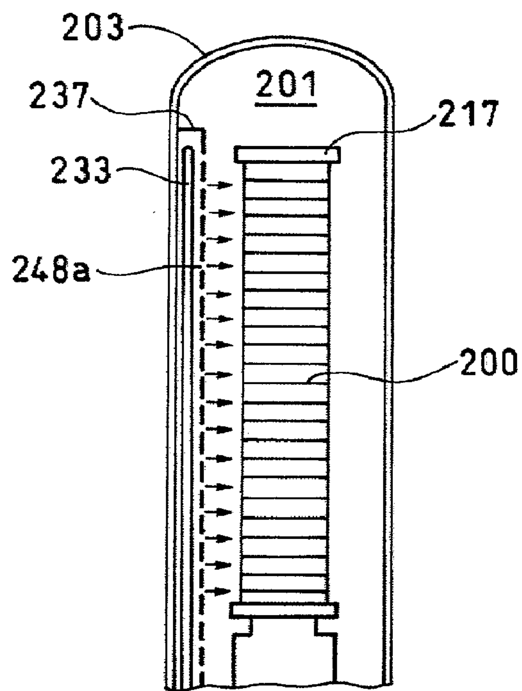


FIG.4

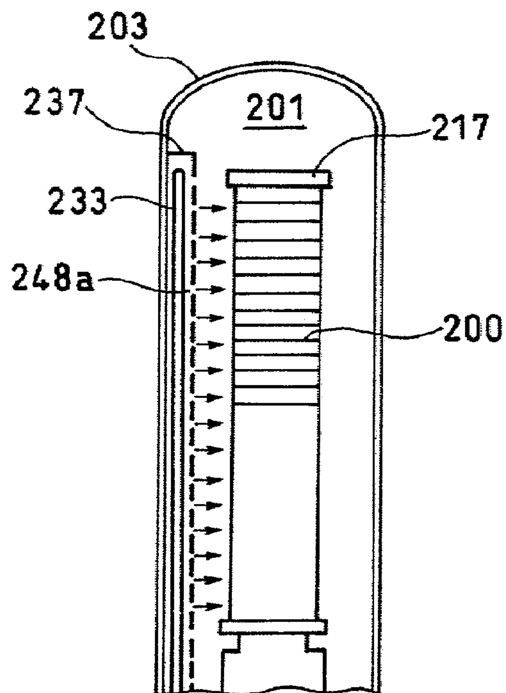


FIG. 5

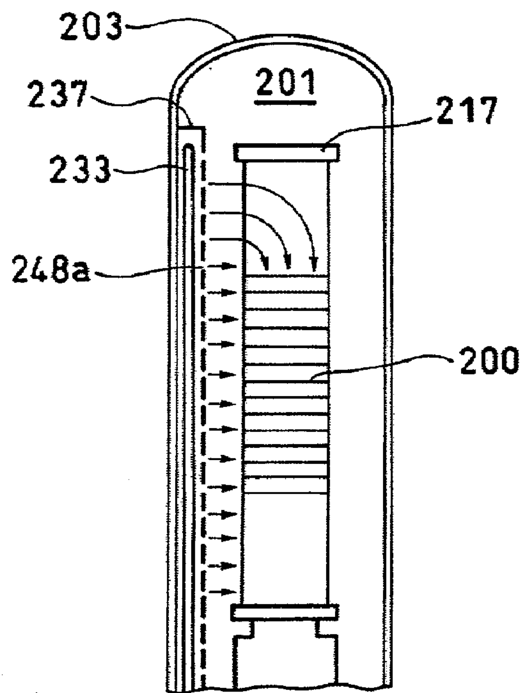


FIG. 6

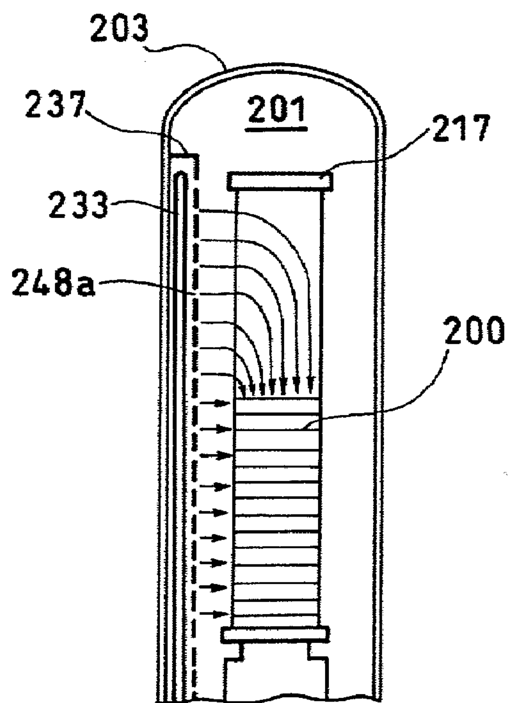


FIG. 7

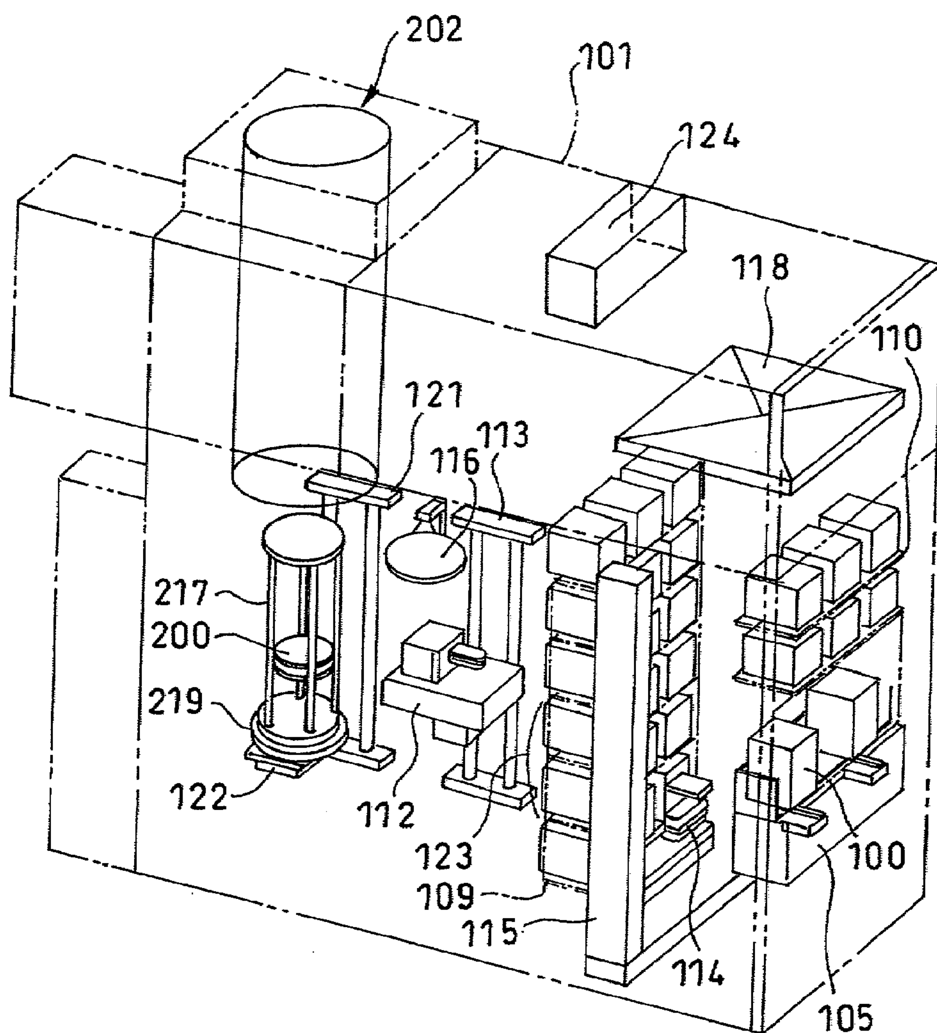
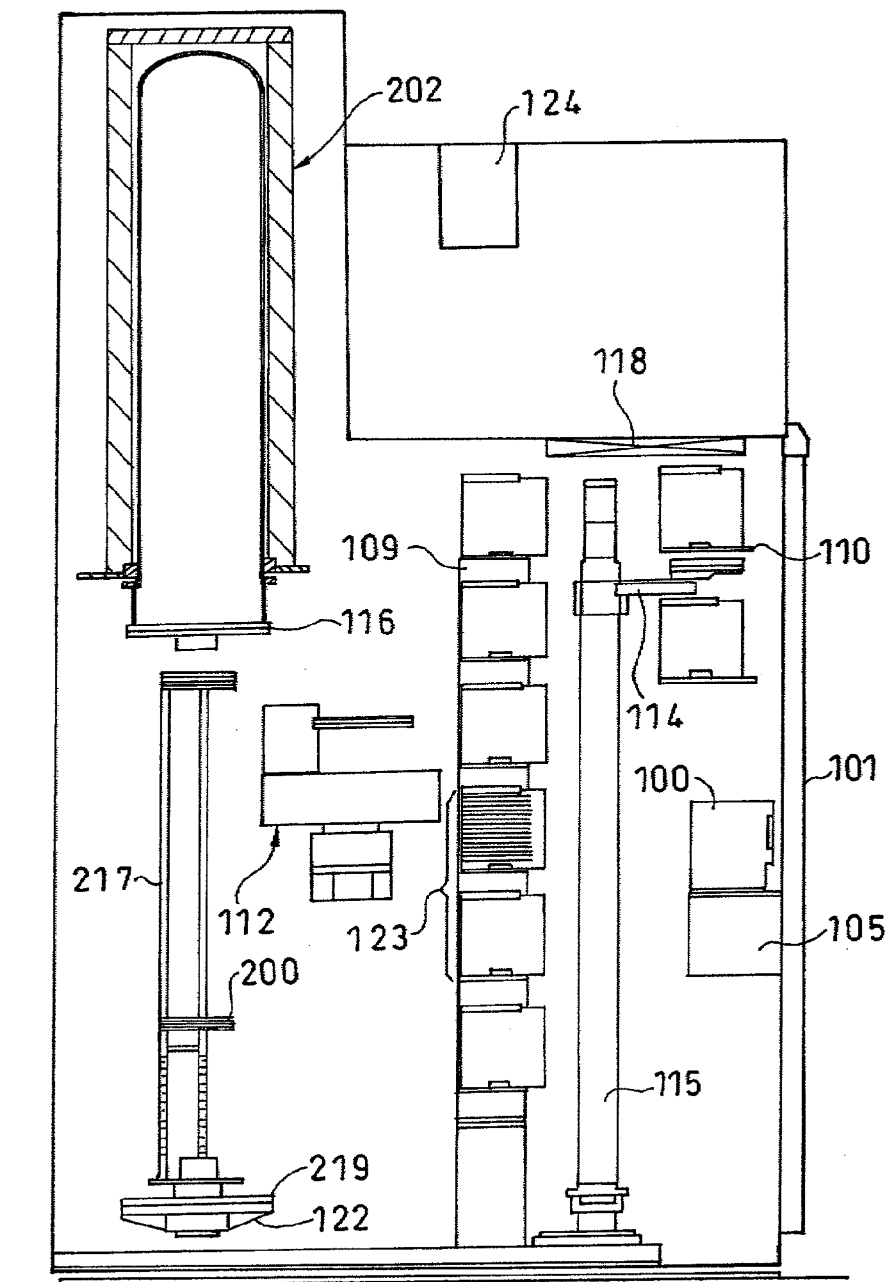


FIG. 8



SUBSTRATE PROCESSING APPARATUS AND PRODUCING METHOD OF SEMICONDUCTOR DEVICE

[0001] This application is a Divisional of copending application Ser. No. 11/664,726 filed on Nov. 29, 2007, which is a National Phase of PCT International Application No. PCT/JP2005/018469 filed on Oct. 5, 2005, which claims the benefit of Patent Application No. 2004-294908 filed in Japan, on Oct. 7, 2004. The entire contents of all of the above applications is hereby incorporated by reference.

[0002] The present invention relates to a substrate processing apparatus and a producing method of a semiconductor device, and more particularly, to a substrate processing apparatus and a producing method of a semiconductor device in which a desired film is produced on a substrate such as a wafer by an ALD (Atomic Layer Decomposition) method.

BACKGROUND ART

[0003] In a substrate processing apparatus and a producing method of a semiconductor device in which a number of substrates are processed at once by using a thermal CVD (Chemical Vapor Deposition) method, the number of substrates loaded in a processing chamber to be processed at one time varies. For example, there are cases in which substrate processing for 50 substrates is carried out or substrate processing for 25 substrates is carried out even when 100 substrates can be processed. In such cases, the total number of substrates is made to be 100 by inserting substrates which are called fill-dummies in a region where product substrates are not disposed.

[0004] However, in such a method in which fill-dummy substrates are inserted, the more the number of the fill-dummy substrates, the more the production cost increases. Therefore, in the thermal CVD method, when a shortage of product wafers occurs, the product wafers are packed and placed in an upstream of gas flow without using the fill-dummies. Film thicknesses among the wafers are made to be unified by adjusting a preset temperature of a heater zone and changing a heat condition. When changing the preset temperature of the heater zone, only the region in which wafers exist is made to be a uniform temperature zone, and other regions are made to be a thermal insulating zone to suppress reactions in the thermal insulating zone, thereby preventing an effect to a wafer processing region (See Japanese Patent Application Publication Laid-open No. 2003-45863).

[0005] The product wafers are packed in the upstream of a gas flow because of the following reason: When there is a space in the upstream side, consumption of SiH_2Cl_2 which is gas for film forming processing for to film processing decreases. On the other hand, self decomposition of breaking down to $SiCl_2$ progresses and further, reaction of SiH_2Cl_2 is blocked because an adsorptive coefficient of $SiCl_2$ is one digit greater than the adsorptive coefficient of SiH_2Cl_2, and film forming speed does not become stable. Hence, to prevent such phenomenon, the product wafers are packed in the upstream of the gas flow.

[0006] Although the fill-dummies are not used in the above described art disclosed in Japanese Patent Application Publication Laid-open No. 2003-45863, heating condition needs to be changed because a thermal CVD method is used.

[0007] This change in heating condition due to the preset temperature change in each zone is carried out based on experiences by previous data, or carried out by correcting temperatures by automatically calculating the preset temperatures of each zone by using an interference line method.

[0008] It is a main object of the present invention to provide a substrate processing apparatus and a producing method of a semiconductor device in which a uniformity of film thicknesses among the substrates can be enhanced without setting a new condition even when the number of product substrates to be held by a holding member is less than the maximum number of the product substrates the holding member is capable of holding.

[0009] According to one aspect of the present invention, there is provided a substrate processing apparatus, comprising:

[0010] a processing chamber;

[0011] a holding member to hold at least a plurality of product substrates in the processing chamber,

[0012] a heating member to heat the substrates,

[0013] a supplying member to alternately supply at least a first reactant and a second reactant into the processing chamber;

[0014] an exhausting port opened to the processing chamber, and

[0015] a control unit,

[0016] wherein the control unit

[0017] executes a processing of forming thin films on the substrates by supplying the first reactant into the processing chamber, removing a surplus of the first reactant after the first reactant has been adsorbed on the product substrates which are held by the holding member, subsequently supplying the second reactant into the processing chamber, to cause the second reactant to react with the first reactant which has been adsorbed on the substrates, and

[0018] executes the processing of forming the thin films in a state where a number of the product substrates is insufficient when a number of the product substrates to be held by the holding member is less than a maximum number of the product substrates which can be held by the holding member.

[0019] According to another aspect of the present invention, there is provided a producing method of a semiconductor device, comprising:

[0020] a first step of allowing a holding member in a processing chamber to hold a plurality of product substrates,

[0021] a second step of heating the substrates,

[0022] a third step of supplying a first reactant into the processing chamber and allowing the first reactant to be adsorbed on the product substrates,

[0023] a forth step of removing a surplus of the first reactant from inside the processing chamber,

[0024] a fifth step of supplying a second reactant into the processing chamber and allowing the second reactant to react with the first reactant which has been adsorbed on the product substrates to form thin films on the substrates, and

[0025] a sixth step of repeating at least the steps 3 to 5 for a predetermined times till the thin films having a desired thickness are formed on the product substrates, wherein

[0026] the steps 1 to 6 are carried out in a state where a number of the product substrates is insufficient when a number of the product substrates to be held by the holding member is less than a maximum number of the product substrates which can be held by the holding member.

[0027] According to still another aspect of the present invention, there is provided a substrate processing apparatus which comprises:

[0028] a processing chamber;

[0029] a holding member to hold a plurality of product substrates in the processing chamber;

[0030] a heating member to heat the substrates;

[0031] a supplying member to alternately supply at least a first reactant and a second reactant into the processing chamber; and

[0032] an exhausting port opened to the processing chamber, wherein

[0033] thin films are formed the substrates by supplying the first reactant, removing a surplus of the first reactant after the first reactant is adsorbed on the substrates, and subsequently supplying the second reactant to cause the second reactant to react with the first reactant which has been adsorbed on the substrates, and

[0034] the apparatus comprises a control unit to execute the processing of forming the thin films in a state where a number of the product substrates is insufficient when a number of the product substrates to be held by the holding member is less than a maximum number of the product substrates which can be held by the holding member.

[0035] According to still another aspect of the present invention, there is provided a producing method of a semiconductor device wherein processing of forming thin films is carried out in a state where a number of the product substrates is insufficient when a number of the product substrates to be held by a holding member is less than a maximum number of the product substrates which can be held by the holding member by using a substrate processing apparatus which comprises:

[0036] a processing chamber;

[0037] a holding member to hold a plurality of product substrates in the processing chamber;

[0038] a heating member to heat the substrates;

[0039] a supplying member to alternately supply at least a first reactant and a second reactant in the processing chamber; and

[0040] an exhausting port opened to the processing chamber, wherein the thin films are formed on the substrates by supplying the first reactant, removing a surplus of the first reactant after the first reactant is adsorbed on the substrates, subsequently supplying the second reactant to cause the second reactant to react with the first reactant which has been adsorbed on the substrate, and the apparatus comprises a control unit to execute the processing of forming the thin films in the state where the number of the product substrates is insufficient when the number of the product substrates to be held by the holding member is less than the maximum number of the product substrates which can be held by the holding member.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] FIG. **1** is a schematic longitudinal sectional view for explaining a vertical substrate processing furnace of a substrate processing apparatus according to preferable embodiments of the present invention.

[0042] FIG. **2** is a schematic transversal sectional view for explaining the vertical substrate processing furnace of the substrate processing apparatus according to the preferable embodiments of the present invention.

[0043] FIG. **3** is a schematic longitudinal sectional view for explaining a loading status of wafers into a boat in the vertical substrate processing furnace of the substrate processing apparatus according to the preferable embodiment of the present invention.

[0044] FIG. **4** is a schematic longitudinal sectional view for explaining the loading status of wafers into the boat in the vertical substrate processing furnace of the substrate processing apparatus according to the preferable embodiments of the present invention.

[0045] FIG. **5** is a schematic longitudinal sectional view for explaining the loading status of wafers into the boat in the vertical substrate processing furnace of the substrate processing apparatus according to the preferable embodiments of the present invention.

[0046] FIG. **6** is a schematic longitudinal sectional view for explaining the loading status of wafers in the boat in the vertical substrate processing furnace of the substrate processing apparatus according to the preferable embodiments of the present invention.

[0047] FIG. **7** is a schematic perspective view for explaining the substrate processing apparatus according to the preferable embodiments of the present invention.

[0048] FIG. **8** is a schematic perspective view for explaining the substrate processing apparatus according to the preferable embodiments of the present invention.

[0049] In preferred embodiments of the present invention, an ALD method is used to form a film instead of a CVD method. The ALD method is a technique for forming a film in such a manner that two (or more) kinds of raw material gases used for forming the film are alternately supplied onto a substrate one kind by one kind under a certain condition (temperature, time or the like) to cause each kind of the gases to be adsorbed on the substrate by one atom layer at a time, thereby forming the film utilizing a surface reaction.

[0050] That is, concerning chemical reaction to be utilized, when an SiN (silicon nitride) film is to be formed, in the ALD method, DCS (SiH_2Cl_2, dichlorosilane) and NH_3 (ammonia) are used, and a high quality film can be formed at a lower temperature of 300 to 600° C. Concerning gas supplying operation, a plurality kinds of reaction gases are supplied alternately one kind by one kind. A thickness of the film is controlled by the number of cycles of reaction gas supplying operations (if a film forming speed is 1 Å/one cycle, and if a film of 20 Å thickness is to be formed, the processing is carried out by 20 cycles).

[0051] In the preferred embodiments of the present invention, thin films are formed on the substrates by supplying a first reactant to a processing chamber, removing a surplus of the first reactant after the first reactant is adsorbed on product substrates which are held by a holding member, subsequently supplying a second reactant into the processing chamber to cause the second reactant to react with the first reactant which has been adsorbed on the substrates. When the number of product substrates to be held by a holding member is less than the maximum number of product substrates which can be held by the holding member, a control unit executes a processing of forming the thin film in a state where the number of product substrates is insufficient.

[0052] When the number of product substrates to be held by the holding member is less than the maximum number of the product substrates which can be held by the holding member, the control unit allows the product substrates to be packed and held on am upstream side of a gas flow of the holding member,

and an exhausting side of the holding member to be a non-holding region, and executes the processing of forming the thin films on the substrates.

[0053] A supplying member is composed of an elongated nozzle which includes a large number of gas jet holes, the holding member is to hold a plurality of substrates so as to be stacked in layers in a longitudinal direction of the nozzle, and the exhausting port is positioned on one end side of the nozzle in the longitudinal direction. When the number of product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member, the control unit allows the product substrates to be packed and held on another end side of the nozzle of the holding member in the longitudinal direction, and executes the processing of forming the thin films on the substrates.

[0054] When the number of product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member, the control unit executes the processing of forming the thin films under a condition of the heating member that is the same as the condition when the maximum number of product substrates which can be held by the holding member is held by the holding member.

[0055] Concerning the product substrates, there are cases where the product substrates are only consisted of production substrates for actually producing semiconductor devices and the product substrates are consisted of the production substrates and side-dummies which are provided above and below the production substrates, and at least one side-dummy is preferably provided above the production substrates and at least one side-dummy is provided below the production substrates.

[0056] In the preferred embodiment of the present invention, the films are formed by the ALD method, which is different from the conventional CVD method in that the thin films are formed on the substrates one atom layer by one atom layer by allowing the second reactant to react with the first reactant which has been adsorbed on the substrates in the ALD method, whereas a vapor-phase reaction is carried out in the conventional CVD method. Therefore, when forming films by the ALD method, differently from the case of the conventional thermal CVD method, there is no need to change the preset temperature of each heater zone so as to make distribution of film thicknesses among the substrates be uniform even when the number of product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member.

[0057] As a result, even when the number of product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member, the processing of forming the thin films can be executed under the condition of the heating member that is the same as the condition when the maximum number of product substrates which can be held by the holding member is held by the holding member.

[0058] However, the film thickness of the film which is formed by the ALD method is influenced by the flow of the reactant gas, and also influenced by density of the gas to which the surfaces of the substrates are exposed. Therefore, even when the number of product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member, the density of the gas to which the surfaces of the substrates are exposed is preferably the same as in the case in which the maximum number of product substrates which can be held by the holding member is held by the holding member.

[0059] Therefore, when the number of the product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member, the product substrates are preferably packed and held in an upstream of a gas flow of the holding member, to form the thin films on the substrates, with the discharging port side of the holding member being the non-holding region.

[0060] When the supplying member is composed of an elongated nozzle which includes a large number of gas jet holes, the holding member holds a plurality of substrates so as to be stacked in layers in a longitudinal direction of the nozzle, the exhausting port is positioned at one end side of the nozzle in the longitudinal direction, and the number of product substrates which are to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member, the product substrates are preferably packed and held on the other end side of the nozzle in the longitudinal direction. to form the thin films on the substrates.

[0061] When the number of product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member, a method of placing the substrates evenly throughout the entire holding member by elongating intervals between the substrates is conceivable instead of packing the substrates in either end of the upstream of the gas flow or the longitudinal direction of the nozzle. According to such method, the intervals between the substrates change from the intervals in the case where the number of the product substrates to be held by the holding member is the maximum number of the substrates which can be held by the holding member, to change the amount of reaction gas which flows in between the substrates. As a result, the film thickness changes and this method is not preferred.

[0062] Next, preferable embodiments of the present invention will be described in detail with reference to the drawings.

[0063] FIG. **1** is a schematic structural view for explaining a vertical type substrate processing furnace according to the present embodiments showing a processing furnace portion in a longitudinal cross section, and FIG. **2** is a schematic structural view for explaining the vertical type substrate processing furnace according to the present embodiments showing the processing furnace portion in a traverse cross section.

[0064] A quartz-made reaction tube **203** is provided as a reaction chamber for processing wafers **200**, which are a substrate, inside a heater **207** which is a heating means. A lower end opening of the reaction tube **203** is air-tightly closed with a seal cap **219**, which is a lid, through an O-ring **220** which is a hermetic member. A thermal insulating member **208** is provided outside the reaction tube **203** and the heater **207**. The thermal insulating member **208** is provided so as to cover an upper end of the heater **207**. At least, the heater **207**, the thermal insulating member **208**, the reaction tube **203** and the seal cap **219** form a processing furnace **202**. The reaction tube **203**, the seal cap **219** and a later-described buffer chamber **237** formed in the reaction tube **203** form a processing chamber **201**. A boat **217**, which is a substrate-holding means, is provided above the seal cap **219** in a standing attitude through a quartz cap **218**. The quartz cap **218** is a

holding body which holds the boat **217**. The boat **217** is inserted into the processing furnace **202**. Plurality of wafers **200** to be batch-processed are loaded vertically in the boat **217** in an axial direction of the tube in a multi-stacked manner in their horizontal postures. The heater **207** heats the wafers **200** inserted into the processing furnace **202** to a predetermined temperature.

[0065] Two gas supply pipes **232***a* and **232***b* are provided as supply pipes for supplying plurality kinds (here, two kinds) of gases to the processing furnace **202**. Reaction gas is supplied from the gas supply pipe **232***a* to the processing chamber **201** through a mass flow controller **241***a* which is a flow rate control means, a valve **243***a* which is an open/close valve and an after-described buffer chamber **237** formed in the reaction tube **203**. Further, reaction gas is supplied from the gas supply pipe **232***b* to the processing chamber **201** through a mass flow controller **241***b* which is a flow rate control means, a valve **243***b* which is an open/close valve, a gas tank **247**, a valve **243***c* which is an open/close valve, and an after-described gas supply unit **249**.

[0066] To the gas supply pipe **232***b*, is fitted a pipe heater (not shown) which can heat the pipe **232***b* up to about 120° C. to prevent the liquefaction of raw material.

[0067] The processing chamber **201** is connected to a vacuum pump **246** which is an exhausting means through a valve **243***d* by a gas exhaust pipe **231** which is an exhaust pipe for exhausting gas, thereby evacuating the processing chamber **201**. The valve **243***d* is an open/close valve which allows and stops the evacuation of the processing chamber **201** by opening and closing the valve **243***d*, and which can adjust pressure of the processing chamber **201** by adjusting its opening degree.

[0068] A buffer chamber **237** which is a gas dispersion space is provided in an arc-shaped space between the wafers **200** and an inner wall of the reaction tube **203** constituting the processing chamber **201**. The buffer chamber **237** is provided with the inner wall of the reaction tube **203** along the stacking direction of the wafers **200** from a lower portion to an upper portion. Gas supply holes **248***a* which are supply holes for supplying gas are formed in an inner wall, at a location near an end thereof, of the buffer chamber **237** which is adjacent to the wafers **200**. The gas supply holes **248***a* are opened toward the center of the reaction tube **203**. The gas supply holes **248***a* have the same opening areas from a lower portion to an upper portion in the stacking direction of the wafers **200** over a predetermined length, and the gas supply holes **248***a* are formed with the same pitch.

[0069] A nozzle **233** is disposed near another end of the buffer chamber **237** opposite to the end at which the gas supply holes **248***a* are provided. The nozzle **233** is disposed along the stacking direction of the wafers **200** from the lower portion to the upper portion of the reaction tube **203**. The nozzle **233** is provided with a plurality of gas supply holes **248***b* which are supply holes for supplying gas. The plurality of gas supply holes **248***b* are disposed over the same predetermined length as in the case of the gas supply holes **248***a* along the stacking direction of the wafers **200**. The plurality of gas supply holes **248***b* and the plurality of gas supply holes **248***a* are disposed so as to respectively correspond to each other one hole by one hole.

[0070] When a pressure difference between the buffer chamber **237** and the processing furnace **202** is small, the opening areas of the gas supply holes **248***b* are preferably the same and the opening pitches may be the same from its upstream side toward its downstream side, but if the pressure difference is great, the opening areas are preferably increased or the opening pitches may be reduced from the upstream side toward the downstream side.

[0071] If the opening areas or the opening pitches of the gas supply holes **248***b* are adjusted from the upstream side to the downstream side, gases can be injected substantially at the same flow rate although flowing speeds of gases are different from one another among each gas supply holes **248***b*. Gas injected from each gas supply hole **248***b* is injected to the buffer chamber **237** and is once introduced, and the flowing speeds of gases are equalized.

[0072] That is, in the buffer chamber **237**, gas particle velocity of gas injected from each gas supply hole **248***b* is moderated and then, the gas is injected into the processing chamber **201** from the gas supply holes **248***a*. During this time, gases injected from each gas supply holes **248***b* have equal flow rates and flowing speeds when the gases were injected from the each gas supply hole **248***a*.

[0073] A rod-like electrode **269** and a rod-like electrode **270** having a thin and long structure are disposed in the buffer chamber **237** such as to extend from an upper portion to a lower portion in the buffer chamber **237**. The rod-like electrode **269** and the rod-like electrode **270** are protected by electrode protection tubes **275** which are protection tubes for protecting the electrodes. One of the first rod-like electrode **269** and the second rod-like electrode **270** is connected to a high frequency power supply **273** through a matching device **272**, and the other is connected to a ground which is a reference potential. As a result, plasma is produced in a plasma producing region **224** between the rod-like electrode **269** and the rod-like electrode **270**.

[0074] The electrode protection tubes **275** can be inserted into the buffer chamber **237** in a state where the rod-like electrode **269** and the rod-like electrode **270** are isolated from atmosphere in the buffer chamber **237**. If the atmosphere in the electrode protection tube **275** is the same as outside air (atmosphere), the rod-like electrode **269** and the rod-like electrode **270** respectively inserted into the electrode protection tubes **275** are oxidized by heat from the heater **207**. Thus, there is provided an inert gas purge mechanism which charges or purges inert gas such as nitrogen into and from the electrode protection tube **275**, to reduce the oxygen concentration to a sufficiently low value, resulting in preventing the rod-like electrode **269** or the rod-like electrode **270** from being oxidized.

[0075] A gas supply unit **249** is provided on the inner wall of the reaction tube **203** at a location away from the gas supply holes **248***a* by about 120°. When a plurality of kinds of gases are supplied to the wafers **200** alternately one kind by one kind by the ALD method to form a film, the gas supply unit **249** is a supply unit which shares gas supply species with the buffer chamber **237**.

[0076] Like the buffer chamber **237**, the gas supply unit **249** also includes third gas supply holes **248***c* which are supply holes for supplying gas at the same pitch to a position adjacent to the wafer. The second gas supply tube **232***b* is connected to the gas supply unit **249** at a lower part thereof.

[0077] When the pressure difference between the buffer chamber **237** and the processing chamber **201** is small, it is preferable that the opening areas of the third gas supply holes **248***c* are equal to each other from the upstream side to the downstream side and the holes **248***c* are arranged at the same opening pitch, but when the pressure difference is great, it is

preferable that the opening areas are increased or the opening pitch is reduced from the upstream side to the downstream side.

[0078] The boat **217** is provided at the central portion in the reaction tube **203**. The plurality of wafers **200** are placed on the boat **217** in the vertical direction at the multi-stacked manner at an equal distance from one another. The boat **217** is brought into and out from the reaction tube **203** by a boat elevator mechanism (not shown). To enhance the uniformity of processing, a boat rotating mechanism **267** which is a rotating means for rotating the boat **217** is provided. If the boat rotating mechanism **267** is rotated, the boat **217** held by the quartz cap **218** is rotated.

[0079] A controller **321** is a control means. The controller **321** is connected to the mass flow controllers **241***a* and **241***b*, the valves **243***a*, **243***b*, **243***c* and **243***d*, the heater **207**, the vacuum pump **246**, the boat rotating mechanism **267**, a boat elevator **212**, the high frequency power supply **273** and the matching device **272**. The controller **321** adjusts the flow rates of the mass flow controllers **241***a* and **241***b*, opens and closes the valves **243***a*, **243***b*, **243***c* and **243***d*, adjust the temperature of the heater **207**, starts and stops the vacuum pump **246**, adjusts the rotation speed of the boat rotating mechanism **267**, controls the vertical motion of the boat elevator **121**, controls the electricity supply to the high frequency power supply **273**, and controls impedance by the matching device **272**.

[0080] Next, an example of forming a SiN film using DCS and $NH_{3_}$ gas by the ALD method will be explained.

[0081] First, wafers **200** on which films are to be formed are loaded on the boat **217** and the boat **217** is brought into the processing furnace **202**. Then, the following three steps are sequentially carried out.

[0082] [Step 1]

[0083] In step 1, NH_3 gas which requires plasma excitation and DCS gas which does not require plasma excitation are allowed to flow together. First, the valve **243***a* provided in the gas supply pipe **232***a* and the valve **243***d* provided in the gas exhaust pipe **231** are opened together, thereby injecting the NH_3 gas, which is supplied from the gas supply pipe **232***a* and a flow rate of which is adjusted by the mass flow controller **241***a*, from the gas supply holes **249***b* of the nozzle **233** to the buffer chamber **237**. High frequency electricity is applied between the rod-like electrodes **269** and **270** from the high frequency power supply **273** through the matching device **272** to plasma-excite NH_3, and the NH_3 is supplied to the processing chamber **201** as an active species, while the processing chamber **201** is exhausted through the gas exhaust pipe **231**. When NH_3 gas is plasma-excited and allowed to flow as the active species, the valve **243***d* is appropriately adjusted such that the pressure in the processing chamber **201** becomes 10 to 100 Pa. The supply flow rate of NH_3 controlled by the mass flow controller **241***a* is 1,000 to 10,000 sccm. Time during which the wafers **200** are exposed to the active species obtained by plasma-exciting NH_3 is 2 to 120 seconds. The temperature of the heater **207** at that time is set to 300 to 600° C. Because NH_3 has a high reacting temperature, NH_3 does not react at the above described temperature of the wafers, which causes NH_3 to be flowed as the active species by plasma-exciting NH_3. Therefore, this processing can be carried out with the temperature of wafers being kept at the set low temperature range.

[0084] When NH_3 is supplied as the active species by plasma-exciting NH_3, the valve **243***b* located upstream of the gas supply pipe **232***b* is opened and the valve **243***c* located downstream of the gas supply pipe **232***b* is closed so that DCS is also allowed to flow. With this, DCS is accumulated in the gas tank **247** provided between the valves **243***b* and **243***c*. At that time, gas flowing into the processing chamber **201** is the active species obtained by plasma-exciting NH_3, and no DCS exists. Therefore, NH_3 does not cause vapor-phase reaction, and NH_3 which has been plasma-excited to be the active species surface-reacts with a foundation film on the wafer **200**.

[0085] [Step 2]

[0086] In step 2, the valve **243***a* of the gas supply pipe **232***a* is closed to stop supply of NH_3. However, the supply of gas to the gas tank **247** is continued. When a predetermined amount of DCS of predetermined pressure is accumulated in the gas tank **247**, the upstream valve **243***b* is also closed to trap DCS in the gas tank **247**. The valve **243***d* of the gas exhaust pipe **231** is left open, the processing chamber **201** is exhausted by the vacuum pump **246** so that the pressure inside the processing chamber **201** is below or equal to 20 Pa, and residual NH_3 is exhausted from the processing chamber **201**. At this time, if the inert gas such as N_2 is supplied into the processing chamber **201**, an effect of exhausting the residual NH_3 is further enhanced. In the gas tank **247**, DCS is accumulated so that the pressure becomes higher or equal to 20,000 Pa. The apparatus is constructed so that a conductance between the gas tank **247** and the processing chamber **201** becomes greater or equal to 1.5×10^{-3} m^3/s. When considering a ratio between a capacity of the reaction tube **203** and a capacity of the gas tank **247** required for the capacity of the reaction tube **203**, the capacity of the gas tank **247** is preferably between 100 and 300 cc in the case where the capacity of the reaction tube **203** is 100 l (100 litters). As for a capacity ratio, the gas tank **247** is preferably between 1/1,000 and 3/1,000 times smaller than the capacity of the reaction chamber.

[0087] [Step 3]

[0088] In step 3, if the exhausting operation in the processing chamber **201** is completed, the valve **243***d* of the gas exhaust pipe **231** is closed to stop the exhausting operation. The valve **243***c* located downstream of the gas supply pipe **232***b* is opened. With this, DCS accumulated in the gas tank **247** is supplied to the processing chamber **201** at a dash. At that time, since the valve **243***d* of the gas exhaust pipe **231** is closed, the pressure in the processing chamber **201** is abruptly increased to about 931 Pa (7 Torr). Time during which DCS is supplied is set to 2 to 4 seconds, time during which the wafers are exposed to the increased pressure atmosphere is set to 2 to 4 seconds, and the total time is set to 6 seconds. The temperature of the wafer is the same as that when NH_3 is supplied and is 300 to 600° C. By supplying DCS, NH_3 on a foundation film surface-react with DCS and an SiN film is formed on the wafer **200**. After the film is formed, the valve **243***c* is closed, the valve **243***d* is opened so that the processing chamber **201** is exhausted to vacuum, residual gas which is DCS after contributing to film forming is exhausted. If an inert gas such as N_2 is supplied to the processing chamber **201**, an effect of exhausting the residual gas which is DCS after contributing to film forming is further enhanced. The valve **243***b* is opened and the supply of DCS to the gas tank **247** starts.

[0089] The above described steps 1 to 3 are set to be one cycle, and the SiN film having a predetermined film thickness is formed on the wafer by repeating this cycle for a plurality of times.

[0090] In the ALD apparatus, the gas adsorbs on the surface of the base film. This amount of adsorption of the gas is

proportional to the pressure of the gas and the exposure time to the gas. Thus, in order to allow a desired certain amount of gas to be adsorbed in short time, there is a need to increase the pressure of the gas in short time. To this extent, in the embodiment, pressure of DCS inside the processing chamber **201** can be increased rapidly because DCS accumulated in the gas tank **247** is supplied instantaneously after the valve **243***d* is closed and desired certain amount of the gas can be adsorbed instantaneously.

[0091] In the embodiment, supplying of NH_3 gas as active species by plasma exciting NH_3 which is a needed step for the ALD method and exhausting of the processing chamber **201** are carried out while DCS is being accumulated in the gas tank **247**. Therefore, a special step of accumulating DCS is not needed. Because DCS is allowed to flow after inside of the processing chamber **201** is exhausted and NH_3 gas is removed, DCS and NH_3 gas do not react with each other while flowing towards the wafers **200**. The supplied DCS is allowed to react effectively only with NH_3 which is adsorbed to the wafer **200**.

[0092] A case in which DCS is accumulated in the gas tank **247** is described above. When the gas tank **247** is not used, the following three steps are orderly executed. When the gas tank **247** is not used, the valve **243***c* at a downstream of the gas supplying tube **232***b* is neither used.

[0093] [Step 1]

[0094] In step 1, first, the valve **243***a* provided in the gas supply pipe **232***a* and the valve **243***d* provided in the gas exhaust pipe **231** are opened together, thereby injecting the NH_3 gas, which is supplied from the gas supply pipe **232***a* and a flow rate of which is adjusted by the mass flow controller **241***a*, from the gas supply holes **248***b* of the nozzle **233** to the buffer chamber **237**. High frequency electricity is applied between the rod-like electrodes **269** and **270** from the high frequency power supply **273** through the matching device **272** to plasma-excite NH_3, and the NH_3 is supplied to the processing chamber **201** as the active species, while the processing chamber **201** is exhausted through the gas exhaust pipe **231**. When NH_3 gas is plasma-excited and allowed to flow as the active species, the processing chamber **201** becomes 10 to 100 Pa. The supply flow rate of NH_3 controlled by the mass flow controller **241***a* is 1,000 to 10,000 sccm. Time during which the wafers **200** are exposed to the active species obtained by plasma-exciting NH_3 is 2 to 120 seconds. The temperature of the heater **207** at that time is set to 300 to 600° C.

[0095] In step 2, the valve **243***a* of the gas supply pipe **232***a* is closed to stop supply of NH_3. The valve **243***d* of the gas exhaust pipe **231** is left open, the gas processing chamber **201** is exhausted so as to have a pressure below 20 Pa by the vacuum pump **246**, and residual NH_3 is exhausted from the processing chamber **201**. At this time, when inert gas such as N_2 is supplied to the processing chamber **201**, the effect of exhausting residual NH_3 can be enhanced.

[0096] [Step 3]

[0097] In step 3, even after the exhaustion of the processing chamber **201** is completed, the valve **243***d* of the gas exhaust pipe **231** is left open, and the valve **243***b* provided on the gas supply pipe **232***b* is opened, thereby supplying the DCS gas, which is supplied from the gas supply pipe **232***b* and a flow rate of which is adjusted by the mass flow controller **243***b*, from the gas supply hole **248***c* of the gas supply unit **249** to the processing chamber **201** while exhausting the DCS gas from the gas exhaust pipe **231**. When the DCS gas is allowed to flow, the pressure in the processing chamber **201** is set to 10 to 100 Pa. The supply flow rate of the DCS gas controlled by the mass flow controller **241***a* is 1,000 to 10,000 sccm. Time during which the wafers **200** are exposed to DCS is 2 to 120 seconds. The temperature of the heater **207** at that time is set to 300 to 600° C. The temperature of the wafers at this time is 300 to 600° C. being the same as the temperature at the time when NH_3 is supplied. The DCS supply causes surface reaction of NH_3 on the base film and DCS form the SiN film on the wafers **200**.

[0098] After the film is formed, the valve **243***b* is closed, the valve **243***d* of the gas supply pipe **231** is left open to exhaust the processing chamber **201** by the vacuum pump **246** so as to be below or equal to 20 Pa, and residual DCS gas after contributing to the film forming is removed. If inert gas such as N_2 is supplied to the processing chamber **201** at this time, the effect of removing the residual DCS gas after contributing to the film forming from the processing chamber **201** is further enhanced.

[0099] The above described steps 1 to 3 are set to be one cycle, and the SiN film having a predetermined film thickness is formed on the wafers by repeating this cycle for a plurality of times.

[0100] Next, descriptions will be given for the cases where the number of product wafers to be held by the boat **217** is the maximum number of the product wafers which the boat **217** can hold (see FIG. **3**) and where the number of product wafers to be held by the boat **217** is less than the maximum number when forming films by using the above described substrate processing apparatus. Regarding the case where the number of wafers **200** for production to be held by the boat **217** is less than the maximum number of product wafers **200** which can be held by the boat **217**, FIG. **4** shows when the product wafers **200** are packed in an upper part of the boat **217**, FIG. **5** shows when the product wafers **200** are loaded in the center part of the boat **217**, and FIG. **6** shows when the product wafers **200** are packed in a lower part of the boat **217**. The product wafers **200** comprise the production substrates which actually produces the semiconductor apparatus, at least one side-dummy wafer provided above the production substrate and at least one side-dummy wafer provided below the production substrate.

[0101] Concerning the reaction gas supply, the reaction gas is supplied from a lateral direction of the wafers **200** through the gas supply holes **248***a* formed on the side wall of the buffer chamber **237** from a lower part to an upper part along the stacking direction of the wafers **200** or the gas supply holes **248***c* (see FIG. **2**) formed on the side wall of the gas supply unit **249** from a lower part to an upper part along the stacking direction of the wafers **200**. The exhaustion is carried out from the exhausting port formed at a lower part of the reaction tube **203** (See FIG. **1**). Therefore, if there is a region in which wafers are not loaded, it is conceived that variation of gas distribution over the entire surfaces of the wafers becomes large because the substantial gas density at the end portions of the wafers increases in a down stream region of the region in which wafers are not loaded and variation of film thickness distribution among the wafers become large. Therefore, in the ALD process, it is desirable that the wafers **200** for production are always placed in the upstream of the gas flow.

[0102] Referring to FIGS. **4** to **6**, as shown in FIG. **4**, density of gas which is received by each wafer when the wafers **200** are packed in the upper part of the boat **217** is the same as the gas density in the case where the maximum

number of wafers **200** are loaded in the boat **217**. Therefore, uniformity among the wafers **200** when the wafers **200** are packed in the upper part is about the same as the uniformity among the wafers **200** when the maximum number of wafers **200** are loaded.

[0103] However, as shown in FIGS. **5** and **6**, when the wafers **200** are loaded in the center part of the boat **217** or in the lower part of the boat **217**, to the upper side wafers among the loaded wafers, more gas is supplied than in the case where the maximum number of wafers **200** are loaded in the boat **217** from the gas supply holes **248***a* and the gas supply holes **248***c* (see FIG. **2**) which are at the upper side of the wafers. Therefore, difference in the gas density between the upper side wafers and the wafers in a lower side becomes prominent and the uniformity among the wafers deteriorates.

[0104] When the maximum loading number of wafers is 50, the uniformity of the film thickness over entire surfaces of the wafers and among wafers are shown in the table 1 for the cases where 50 wafers **200** are loaded in the boat **217**, 25 wafers **200** are packed in the upper part of the boat **217**, and 25 wafers **200** are packed in the lower part of the boat **217**.

TABLE 1

	Distribution of film thickness		
	Full Charge 50 wafers	Upper packed 25 wafers	Lower packed 25 wafers
Top wafer surface (%)	1.2	1.6	2.6
Bot wafer surface (%)	1.0	1.3	1.9
Among wafers (%)	1.7	0.4	1.8

[0105] Concerning the condition for film forming, the temperature for film forming was 550° C., and the following cycle is repeated 10 times. The cycle was as follows: DCS was flowed for 2 seconds with the flow rate of 15 sccm and then, inside the reaction tube **203** is purged for 4 seconds, NH_3 excited by high frequency power of 0.4 kW was flowed for 3 seconds with the flow rate of 4 slm, and the inside of the reaction tube **203** was purged for 4 seconds. The heating condition is the same for the cases where 50 wafers **200** are loaded on the boat **217** and where 25 wafers **200** are loaded on the boat **217**, and temperature inclination is not set even for the case where 25 wafers **200** are loaded on the boat **217**. The film forming is carried out in an apparatus in which neither the DCS gas tank **247** nor the valve **243***c* at the downstream side of the gas supply pipe **232***b* is used.

[0106] As shown in Table 1, when 25 wafers **200** are packed in the upper part of the boat **217**, the same result is obtained as in the case where 50 wafers **200** are loaded in the boat **217**. However, when 25 wafers **200** are packed in the lower part of the boat **217**, it shows that the uniformity of the film thickness deteriorates. Here, Top wafer surface indicates over the entire surface of the wafer which is loaded at very top among the loaded wafers, and Bot wafer surface indicates over the entire surface of the wafer which is loaded at very bottom among the loaded wafers.

[0107] Next, an outline of the substrate processing apparatus of the embodiment will be described with reference to FIGS. **7** and **8**.

[0108] A cassette stage **105** as a holding tool delivery member which deliveries a cassette **100** as a substrate accommodating container between a casing **101** and an external transfer apparatus (not shown) is provided on a front surface side in the casing **101**. A cassette elevator **115** as elevator means is provided on a rear side of the cassette stage **105**. A cassette loader **114** as transfer means is mounted on the cassette elevator **115**. A cassette shelf **109** as placing means of the cassette **100** is provided on the rear side of the cassette elevator **115**, and an auxiliary cassette shelf **110** is provided also above the cassette stage **105**. A clean unit **118** is provided above the auxiliary cassette shelf **110** so that clean air can flow into the casing **101**.

[0109] The processing furnace **202** is provided above a rear portion of the casing **101**. A boat elevator **121** as elevator means is provided below the processing furnace **202**. The boat elevator **121** vertically moves the boat **217** as the substrate holding means to and from the processing furnace **202**. The boat **217** holds the wafers **200** as substrates in the multi-stacked manner in their horizontal attitudes. The seal cap **219** as a lid is mounted on a tip end of a vertically moving member **122** which is mounted on the boat elevator **121**, and the seal cap **219** vertically supports the boat **217**. A loading elevator **113** as elevator means is provided between the boat elevator **121** and the cassette shelf **109**. A wafer loader **112** as transfer means is mounted on the loading elevator **113**. A furnace opening shutter **116** as shielding means is provided by the side of the boat elevator **121**. The furnace opening shutter **116** has an opening/closing mechanism and air-tightly closes a lower side of the processing furnace **202**.

[0110] The cassette **100** in which the wafers **200** are rotated through 90° by the cassette stage **105** such that wafers **200** are brought into the cassette stage **105** from an external transfer apparatus (not shown) and the wafers **200** assume the horizontal attitudes. The cassette **100** is transferred to the cassette shelf **109** or the auxiliary cassette shelf **110** from the cassette stage **105** by cooperation of vertical movement and lateral movement of the cassette elevator **115** and forward and backward movement and rotational movement of the cassette loader **114**.

[0111] The cassette shelf **109** includes a transfer shelf **123** in which cassette **100** to be transferred by the wafer loader **112** is accommodated. The cassette **100** on which the wafers **200** are set is transferred to the transfer shelf **123** by the cassette elevator **115** and the cassette loader **114**.

[0112] If the cassette **100** is transferred to the transfer shelf **123**, the wafers **200** are loaded on the boat **217** which is lowered from the transfer shelf **123** by cooperation of forward and backward motion and rotational motion of the wafer loader **112** and vertical motion of the loading elevator **113**.

[0113] If a necessary number of wafers **200** are loaded on the boat **217**, the boat **217** is inserted into the processing furnace **202** by the boat elevator **121**, and the processing furnace **202** is air-tightly closed with the seal cap **219**. In the air-tightly closed processing furnace **202**, the wafers **200** are heated, processing gas is supplied into the processing furnace **202**, and the wafers **200** are processed.

[0114] If the processing of the wafers **200** is completed, the wafers **200** are moved to the cassette **100** of the transfer shelf **123** from the boat **217** following the above procedure in reverse, the cassette **100** is moved to the cassette stage **105** from the transfer shelf **123** by the cassette loader **114**, and is transferred out from the casing **101** by the external transfer apparatus (not shown). In the state in which the boat **217** is lowered, the furnace opening shutter **116** air-tightly closes the lower surface of the processing furnace **202** to prevent outside air from entering into the processing furnace **202**.

[0115] The transfer motions of the cassette loader **114** and the like are controlled by transfer control means **124**.

[0116] The entire disclosure of Japanese Patent Application No. 2004-294908 filed on Oct. 7, 2004 including specification, claims, drawings and abstract are incorporated herein by reference in its entirety.

[0117] Although various exemplary embodiments have been shown and described, the invention is not limited to the embodiments shown. Therefore, the scope of the invention is intended to be limited solely by the scope of the claims that follow.

[0118] As explained above, according to the preferred embodiments of the present invention, the uniformity of the film thickness among the substrates can be enhanced without setting new condition even in the case were the number of product substrates to be held by the holding member is less than the maximum number of product substrates which can be held by the holding member.

[0119] As a result, the present invention can especially preferably be utilized for a semiconductor wafer processing apparatus and a producing method of a semiconductor device.

1. A substrate processing apparatus, comprising:
a processing chamber;
a holding member to hold at least a plurality of product substrates in the processing chamber,
a heating member to heat the substrates,
a supplying member to alternately supply at least a first reactant and a second reactant into the processing chamber;
an exhausting port opened to the processing chamber, and
a control unit, wherein the control unit
executes a processing of forming thin films on the substrates by supplying the first reactant into the processing chamber, removing a surplus of the first reactant after the first reactant has been adsorbed on the product substrates which are held by the holding member, subsequently supplying the second reactant into the processing chamber, to cause the second reactant to react with the first reactant which has been adsorbed on the substrates, and
executes the processing of forming the thin films in a state where a number of the product substrates is insufficient when a number of the product substrates to be held by the holding member is less than a maximum number of the product substrates which can be held by the holding member.

2. A substrate processing apparatus, comprising:
a processing chamber;
a holding member to hold at least a plurality of product substrates in the processing chamber, the product substrates packed in said holding member in a longitudinal direction from a top of said processing chamber to a bottom of said processing chamber,
a heating member to heat the substrates,
a supplying member to alternately supply at least a first reactant and a second reactant into the processing chamber;
an exhausting port opened to the processing chamber, and
a control unit, wherein the control unit
executes a processing of forming thin films on the substrates by supplying the first reactant into the processing chamber, removing a surplus of the first reactant after the first reactant has been adsorbed on the product substrates which are held by the holding member, subsequently supplying the second reactant into the processing chamber, to cause the second reactant to react with the first reactant which has been adsorbed on the substrates, and
allows the product substrates to be packed at the top of said processing chamber and held on an upstream side of a gas flow of the holding member and the exhausting port side of the holding member to be a non-holding region, and executes the processing of forming the thin films on the substrates when the number of the product substrates to be held by the holding member is less than the maximum number of the product substrates which can be held by the holding member.

3. A substrate processing apparatus as recited in claim **2**, wherein
the control unit executes the processing of forming the thin films under the same condition of the heating member as when the maximum number of product substrates are held by the holding member, when the number of the product substrates to be held by the holding member is less than the maximum number of the product substrates which can be held by the holding member.

4. A producing method of a semiconductor device, comprising:
a first step of allowing a holding member in a processing chamber to hold a plurality of product substrates, the product substrates packed in said holding member in a longitudinal direction from a top of said processing chamber to a bottom of said processing chamber,
a second step of heating the substrates,
a third step of supplying a first reactant into the processing chamber and allowing the first reactant to be adsorbed on the product substrates,
a fourth step of removing a surplus of the first reactant from inside the processing chamber,
a fifth step of supplying a second reactant into the processing chamber and allowing the second reactant to react with the first reactant which has been adsorbed on the product substrates to form thin films on the substrates, and
a sixth step of repeating at least the steps 3 to 5 for a predetermined times till the thin films having a desired thickness are formed on the product substrates, wherein
the steps 1 to 6 are carried out under conditions that allow the product substrates to be packed at the top of said processing chamber and held on an upstream side of a gas flow of the holding member and an exhausting port side of the holding member to be a non-holding region when a number of the product substrates to be held by the holding member is less than a maximum number of the product substrates which can be held by the holding member.

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