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Substrate processing apparatus, substrate holding apparatus, and method of manufacturing semiconductor device

Abstract

There is provided a technique that includes a process chamber configured to process at least one substrate; a microwave generator configured to generate a microwave; a substrate holder configured to load and hold the at least one substrate; and a rotator which includes an output shaft configured to support the substrate holder and an input shaft installed at an off-centered position with respect to the output shaft.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) This application is based upon and claims the benefit of priority from Japanese Patent

Application No. 2021-015035, filed on Feb. 2, 2021, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

(2) The present disclosure relates to a substrate processing apparatus, a substrate holding apparatus, and a method of manufacturing a semiconductor device.

BACKGROUND

(3) As one process of manufacturing a semiconductor device, there is known, for example, a modifying process, which is represented by an annealing process of modifying a composition of a crystal structure of a thin film formed on a surface of a substrate or restoring a crystal defect or the like in a formed thin film by heating the substrate in a process chamber using a heater. In recent years, semiconductor devices have become remarkably miniaturized and highly integrated. Along with this, there is a demand for a modifying process on a high-density substrate in which a pattern having a high aspect ratio is formed. As a method for the modifying process on such a high-density substrate, for example, a heat treatment method using an electromagnetic wave has been studied.

SUMMARY

(4) A rotation axis of a boat rotator and a rotation axis of the wafer are on the same straight line. In induction heating of radiating an electromagnetic wave to a wafer, there is a possibility that a thick portion and a thin portion appear in a circumferential direction due to an influence of a standing wave corresponding to a wavelength and a frequency of the electromagnetic wave, which makes the film thickness uniformity deteriorate.

(5) Some embodiments of the present disclosure provide a technique capable of improving a film thickness uniformity.

(6) According to some embodiments of the present disclosure, there is provided a technique that includes a process chamber configured to process at least one substrate; a microwave generator configured to generate a microwave; a substrate holder configured to load and hold of the at least one substrate; and a rotator which includes an output shaft configured to support the substrate holder and an input shaft installed at an off-centered position with respect to the output shaft.

Description

BRIEF DESCRIPTION OF DRAWINGS

(1) The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the present disclosure.

(2) FIG. **1** is a vertical cross-sectional view in which a schematic configuration of a substrate processing apparatus suitably used in some embodiments of the present disclosure is shown at a position of a process furnace.

(3) FIG. **2** is a cross-sectional view showing a schematic configuration of a substrate processing apparatus suitably used in some embodiments of the present disclosure.

(4) FIG. **3** is a schematic configuration diagram in which a process furnace portion of a substrate processing apparatus suitably used in some embodiments of the present disclosure is shown in a vertical cross-sectional view.

(5) FIG. **4** is a vertical cross-sectional view in which a schematic configuration of a substrate processing apparatus suitably used in some embodiments of the present disclosure is shown at a position of a cooling chamber.

(6) FIG. **5**A is a diagram schematically showing a method of transferring a wafer to a cooling chamber, and FIG. **5**B is a diagram schematically showing a method of transferring the cooled wafer from the cooling chamber.

(7) FIG. **6** is a schematic configuration diagram of a controller of a substrate processing apparatus suitably used in some embodiments of the present disclosure.

(8) FIG. **7** is a diagram showing a flow of a substrate processing process according to some embodiments of the present disclosure.
(9) FIG. **8** is a schematic configuration diagram in which a boat, a mounting table and a drive mechanism of a substrate processing apparatus suitably used in some embodiments of the present disclosure are shown in a vertical cross-sectional view.
(10) FIG. **9** is a schematic configuration diagram in which a drive mechanism of a substrate processing apparatus suitably used in some embodiments of the present disclosure is shown in a vertical cross-sectional view.
(11) FIG. **10** is a schematic configuration diagram in which a drive mechanism of a substrate processing apparatus suitably used in some embodiments of the present disclosure is shown in a top view.
(12) FIG. **11** is a diagram illustrating rotation and revolution of wafers performed by a drive mechanism of a substrate processing apparatus suitably used in some embodiments of the present disclosure and is a view showing a case where centers of rotation of the wafers and an axis of an output portion of the drive mechanism are not eccentric.
(13) FIG. **12** is a diagram illustrating rotation and revolution of wafers performed by a drive mechanism of a substrate processing apparatus suitably used in some embodiments of the present disclosure and is a view showing a case where centers of rotation of the wafers and an axis of an output portion of the drive mechanism are eccentric.

DETAILED DESCRIPTION

(14) Reference will now be made in detail to various embodiments, examples of which are illustrated in the accompanying drawings. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the present disclosure. However, it will be apparent to one of ordinary skill in the art that the present disclosure may be practiced without these specific details. In other instances, well-known methods, procedures, systems, and components have not been described in detail so as not to unnecessarily obscure aspects of the various embodiments.
(15) Hereinafter, some embodiments of the present disclosure will be described with reference to FIGS. **1** to **12**. Throughout the drawings, the same or corresponding configurations are designated by the same or corresponding reference numerals, and the duplicate description thereof is omitted. The drawings used in the following description are all schematic. The dimensional relationship of each element on the drawings, the ratio of each element, and the like do not always match the actual ones. Further, even between the drawings, the dimensional relationship of each element, the ratio of each element, and the like do not always match.
(16) (1) Configuration of Substrate Processing Apparatus
(17) The substrate processing apparatus **100** according to embodiments is configured as a single-substrate heat treatment apparatus that performs various heat treatments on one wafer or a plurality of wafers. The substrate processing apparatus **100** will be described as an apparatus that performs an annealing process (modifying process) using an electromagnetic wave described later. In the substrate processing apparatus **100** of the present embodiments, a FOUP (Front Opening Unified Pod hereinafter referred to as a pod) **110** is used as a storage container (carrier) in which wafers **200** as substrates are accommodated. The pod **110** is also used as a transfer container for transferring the wafers **200** between various substrate processing apparatuses.
(18) As shown in FIGS. **1** and **2**, the substrate processing apparatus **100** includes a transfer housing **202** having a transfer chamber **203** for transferring the wafers **200** therein and cases **102-1** and **102-2** installed on a side wall of the transfer housing **202** and having process chambers **201-1** and **201-2** for processing the wafers **200** therein as process containers to be described. Further, a cooling case **109** that forms a cooling chamber **204**, which will be described later, is installed between the process chambers **201-1** and **201-2**.
(19) A load port unit (LP) **106**, as a pod opening/closing mechanism, for opening and closing a lid

of the pod **110** and loading and unloading the wafer **200** into and out of the transfer chamber **203** is arranged on a right side in FIG. **1** (a lower side in FIG. **2**), which is a front side of the transfer housing **202**. The load port unit **106** includes a housing **106***a*, a stage **106***b*, and an opener **106***c*. The stage **106***b* is configured to mount the pod **110** thereon and bring the pod **110** close to a substrate loading/unloading port **134** formed on a front side of the housing of the transfer chamber **203**. The opener **106***c* is configured to open and close a lid (not shown) installed in the pod **110**. Further, the load port unit **106** may have a function capable of purging an inside of the pod **110** with a purge gas such as an N.sub.2 gas or the like. In addition, the transfer housing **202** has a purge gas circulation structure, which will be described later, for circulating a purge gas such as an N.sub.2 gas or the like in the transfer chamber **203**.
(20) Gate valves (GV) **205-1** and **205-2**, which are configured to open and close the process chambers **201-1** and **201-2**, are arranged on a left side in FIG. **1** (an upper side in FIG. **2**), which is a rear side of the transfer housing **202**. In the transfer chamber **203**, a substrate transfer robot as a substrate transfer mechanism for transferring the wafer **200** and a transfer machine **125** as a substrate transfer part are installed. The transfer machine **125** includes tweezers (arms) **125***a***-1** and **125***a***-2** as mounting parts on which the wafer **200** is mounted, a transfer device **125***b* capable of horizontally rotating or linearly moving each of the tweezers **125***a***-1** and **125***a***-2**, and a transfer device elevator **125***c* which moves up and down the transfer device **125***b*. By a continuous operation of the tweezers **125***a***-1** and **125***a***-2**, the transfer device **125***b*, and the transfer device elevator **125***c*, the wafer **200** can be charged into and discharged from a boat (substrate holder) **217**, the cooling chamber **204**, or the pod **110**. Hereinafter, the cases **102-1** and **102-2**, the process chambers **201-1** and **201-2**, and the tweezers **125***a***-1** and **125***a***-2** will be simply referred to as the case **102**, the process chamber **201**, and the tweezers **125***a* unless it is not needed to distinguish them in the description thereof.
(21) The tweezer **125***a***-1** is made of an ordinary aluminum material and is used for transferring a wafer of a low temperature or a room temperature. The tweezer **125***a***-2** is made of a material such as aluminum or quartz having high heat resistance and poor thermal conductivity and is used for transferring a wafer of a high temperature or a room temperature. That is, the tweezer **125***a***-1** is a substrate transfer part for a low temperature, and the tweezer **125***a***-2** is a substrate transfer part for a high temperature. The tweezer **125***a***-2** for high temperature may be configured to have heat resistance at, for example, 100 degrees C. or higher, more desirably 200 degrees C. or higher. A mapping sensor may be installed on the tweezer **125***a***-1** for low temperature. By installing the mapping sensor on the tweeters **125***a***-1** for low temperature, it is possible to confirm the number of wafers **200** in the load port unit **106**, the number of wafers **200** in the process chamber **201**, and the number of wafers **200** in the cooling chamber **204**.
(22) In some embodiments, the tweezer **125***a***-1** is described as the tweezer for low temperature, and the tweezer **125***a***-2** is described as the tweezer for high temperature. However, the present disclosure is not limited thereto. The tweezer **125***a***-1** may be made of a material such as aluminum or quartz having high heat resistance and poor thermal conductivity and may be used for transferring a wafer having a high temperature or a room temperature. The tweezers **125***a***-2** may be made of aluminum and used for transferring a wafer having a low temperature or a room temperature. Further, both the tweezers **125***a***-1** and **125***a***-2** may be made of a material such as aluminum or a quartz member having high heat resistance and poor thermal conductivity.
(23) (Process Furnace)
(24) In region A surrounded by a broken line in FIG. **1**, there is installed a process furnace having a substrate processing structure as shown in FIG. **3**. As shown in FIG. **2**, a plurality of process furnaces is installed in the present embodiments. Since configurations of the process furnaces are the same, one process furnace configuration will be described, and the descriptions of the other process furnace configuration will be omitted.
(25) As shown in FIG. **3**, the process furnace includes a case **102** as a cavity (process container)

made of a material such as a metal or the like that reflects an electromagnetic wave. Further, a cap flange (closing plate) **104**, which is made of a metallic material, is configured to close an upper end of the case **102** via an O-ring as a sealing member (not shown). Inner spaces of the case **102** and the cap flange **104** are mainly configured as a process chamber **201** for processing a substrate such as a silicon wafer or the like. A reaction tube (not shown) made of quartz through which an electromagnetic wave transmits, may be installed inside the case **102**. Also, the process container may be configured such that an interior of the reaction tube serves as a process chamber. Further, the process chamber **201** may be configured by a case **102** having a closed ceiling without installing the cap flange **104**.

(26) A mounting table **210** is installed in the process chamber **201**, and a boat **217**, which is a substrate holder that is configured to load and hold a plurality of wafers **200** as substrates, is mounted on the upper surface of the mounting table **210**. In the boat **217**, the wafers **200** to be processed and susceptors **103***a* and **103***b* placed in a vertical direction of the wafers **200** so as to interpose the wafers **200** therebetween are held at predetermined intervals. The susceptors **103***a* and **103***b* are configured by silicon plates (Si plates) made of, for example, polycrystalline silicon of a columnar crystal structure solidified in a vertical direction (a direction perpendicular to the wafers **200**) and having isotropic thermal conductivity without a crystal orientation. The susceptors **103***a* and **103***b* are arranged above and below the wafers **200** to suppress concentration of electric field strength on the edges of the wafers **200**. That is, the susceptors **103***a* and **103***b* are to suppress absorption of an electromagnetic wave for the edges of the wafers **200**. Further, since a heat generation amount in the susceptors **103***a* and **103***b* is larger than a heat generation amount in the wafers **200**, heating elements are arranged above and below the wafers **200**. Thus, a heat retention property (heat insulating property) becomes large, and variation in a temperature inside the wafers becomes small. Further, quartz plates **101***a* and **101***b* as heat insulating plates may be held on the upper and lower surfaces of the susceptors **103***a* and **103***b* at predetermined intervals. In this specification, the quartz plates **101***a* and **101***b* and the susceptors **103***a* and **103***b* are respectively made of the same components and will be referred to as a quartz plate **101** and a susceptor **103** below unless there is a need to explain them separately.

(27) The case **102** as a process container has, for example, a circular cross section and is configured as a flat closed container. Further, the transfer housing **202** as a lower container is made of, for example, a metallic material such as aluminum (Al) or stainless steel (SUS), quartz, or the like. A space surrounded by the case **102** may be referred to as a process chamber **201** or a reaction area **201** as a process space, and a space surrounded by the transfer housing **202** may be referred to as a transfer chamber or a transfer area **203** as a transfer space. It may not be limited that the process chamber **201** and the transfer chamber **203** are configured to be adjacent to each other in a horizontal direction as in the present embodiments but they may be configured to be adjacent to each other in a vertical direction to move up and down a substrate holder having a predetermined structure.

(28) As shown in FIGS. **1**, **2** and **3**, a substrate loading/unloading port **206** adjacent to a gate valve **205** is installed on a side surface of the transfer housing **202**, and the wafer **200** is moved between the process chamber **201** and the transfer chamber **203** through the substrate loading/unloading port **206**. A choke structure having a length of ¼ wavelength of an electromagnetic wave in use is installed around the gate valve **205** or the substrate loading/unloading port **206**, as a measure against leakage of an electromagnetic wave to be described later.

(29) An electromagnetic wave supplier as a heater described in detail later is installed on a side surface of the case **102**. An electromagnetic wave such as a microwave or the like supplied from the electromagnetic wave supplier is introduced into the process chamber **201** to heat the wafers **200** and the like, thereby processing the wafers **200**.

(30) The mounting table **210** is supported by a shaft **255** as a rotating shaft. The shaft **255** is connected to a drive mechanism **267** as a rotator that performs a rotation operation at the bottom

and outside of the process chamber **201**. By operating the drive mechanism **267** to rotate the shaft **255** and the mounting table **210**, it is possible to rotate the wafers **200** mounted on the boat **217**. The details of the drive mechanism **267** will be described later.
(31) In this regard, the mounting table **210** may be configured to move up and down by the drive mechanism **267** such that the wafer **200** is located at a wafer transfer position in conformity with a height of the substrate loading/unloading port **206** at the time of transferring the wafer **200**, and may be configured to move up and down by the drive mechanism **267** to a processing position (wafer processing position) in the process chamber **201**.
(32) An exhauster, which is configured to exhaust an atmosphere in the process chamber **201**, is installed below the process chamber **201** and at an outer peripheral side of the mounting table **210**. As shown in FIG. **3**, an exhaust port **221** is installed in the exhauster. An exhaust pipe **231** is connected to the exhaust port **221**. A pressure regulator **244** such as an APC valve or the like, which controls a valve opening degree according to a pressure in the process chamber **201**, and a vacuum pump **246** are sequentially connected to the exhaust pipe **231** in series.
(33) In this regard, the pressure regulator **244** is not limited to the APC valve as long as an exhaust amount can be adjusted by receiving pressure information in the process chamber **201** and a feedback signal from a pressure sensor **245** to be described later. A typical opening/closing valve and a pressure regulation valve may be used together.
(34) An exhauster (also referred to as an exhaust system or an exhaust line) is mainly composed of the exhaust port **221**, the exhaust pipe **231**, and the pressure regulator **244**. Exhaust ports may be installed to surround the mounting table **210** so as to be capable of exhaust a gas from the entire circumference of the wafer **200**. Further, the vacuum pump **246** may be added to the configuration of the exhauster.
(35) In the cap flange **104**, there is installed a gas supply pipe **232** configured to supply processing gases such as an inert gas, a precursor gas, and a reaction gas for various substrate processing processes into the process chamber **201**. In the gas supply pipe **232**, a mass flow controller (MFC) **241**, which is a flow rate controller (flow rate control part), and a valve **243**, which is an opening/closing valve, are installed sequentially from an upstream side thereof. For example, a nitrogen (N.sub.2) gas source, which is an inert gas source, is connected to an upstream side of the gas supply pipe **232** and is configured to supply a N.sub.2 gas into the process chamber **201** via the MFC **241** and the valve **243**. When using different gases for substrate processing, the different gases can be supplied by using a configuration in which a gas supply pipe provided with an MFC, which is a flow rate controller, and a valve, which is an opening/closing valve, sequentially from the upstream side thereof is connected to the gas supply pipe **232** on a downstream side of the valve **243**. A gas supply pipe provided with an MFC and a valve may be installed for each gas type.
(36) A gas supply system (gas supplier) is mainly composed of the gas supply pipe **232**, the MFC **241**, and the valve **243**. When an inert gas is allowed to flow in the gas supply system, the gas supply system is also referred to as an inert gas supply system. As the inert gas, in addition to the N.sub.2 gas, it may be possible to use, for example, a rare gas such as an Ar gas, a He gas, a Ne gas, a Xe gas, or the like.
(37) A temperature sensor **263** as a non-contact-type temperature measurement device is installed on the cap flange **104**. By adjusting an output of a below-described microwave oscillator (microwave generator) **655** based on temperature information detected by the temperature sensor **263**, the substrate is heated so that the substrate temperature has a desired temperature distribution. The temperature sensor **263** is composed of a radiation thermometer such as an IR (Infrared Radiation) sensor or the like. The temperature sensor **263** is installed so as to measure a surface temperature of the quartz plate **101***a* or a surface temperature of the wafer **200**. When the susceptor as the heating element described above is installed, the temperature sensor **263** may be configured to measure a surface temperature of the susceptor. The temperature of the wafer **200** (wafer temperature) described in the present embodiments refers to a wafer temperature converted by

temperature conversion data to be described later, that is, an estimated wafer temperature, a temperature obtained by directly measuring a temperature of the wafer **200** with the temperature sensor **263**, or both.

(38) By acquiring a transition of a temperature change for each of the quartz plate **101** or the susceptor **103** and the wafer **200** in advance by the temperature sensor **263**, the temperature conversion data indicative of correlation between a temperature of the quartz plate **101** or the susceptor **103** and a temperature of the wafer **200** may be stored in the memory device **121***c* or the external memory device **123**. By creating the temperature conversion data in advance in this way, the temperature of the wafer **200** can be estimated by measuring the temperature of the quartz plate **101** alone. The output of the microwave oscillator **655**, that is, the heater can be controlled based on the estimated temperature of the wafer **200**.

(39) The temperature sensor is not limited to the radiation thermometer described above. The temperature may be measured by a thermocouple, or the temperature may be measured by using a thermocouple and a non-contact-type thermometer in combination. However, when the temperature is measured by the thermocouple, it is needed to arrange the thermocouple in the vicinity of the wafer **200** to measure the temperature. That is, since it is needed to arrange the thermocouple in the process chamber **201**, the thermocouple itself may be heated by the microwave supplied from a microwave oscillator described later, which makes it difficult to accurately measure the temperature. Therefore, it is desirable to use a non-contact-type thermometer as the temperature sensor **263**.

(40) Further, the temperature sensor **263** is not limited to being installed on the cap flange **104** but may be installed on the mounting table **210**. Further, the temperature sensor **263** may not be directly installed on the cap flange **104** or the mounting table **210** but may be configured to indirectly measure the temperature by reflecting the radiation light from a measurement window installed on the cap flange **104** or the mounting table **210** with a mirror or the like. Further, the temperature sensor **263** is not limited to one. A plurality of temperature sensors **263** may be installed.

(41) Electromagnetic wave introduction ports **653-1** and **653-2** are installed on a side wall of the case **102**. One ends of waveguides **654-1** and **654-2** for supplying electromagnetic waves (microwaves) into the process chamber **201** are connected to the electromagnetic wave introduction ports **653-1** and **653-2**, respectively. Microwave oscillators (electromagnetic wave sources) **655-1** and **655-2** as heating sources for heating by supplying electromagnetic waves into the process chamber **201** are connected to the other ends of the waveguides **654-1** and **654-2**, respectively. The microwave oscillators **655-1** and **655-2** supply electromagnetic waves such as microwaves or the like to the waveguides **654-1** and **654-2**, respectively. Further, as the microwave oscillators **655-1** and **655-2**, magnetrons, klystrons, and the like are used. Hereinafter, the electromagnetic wave introduction ports **653-1** and **653-2**, the waveguides **654-1** and **654-2**, and the microwave oscillators **655-1** and **655-2** will be described as an electromagnetic wave introduction port **653**, a waveguide **654**, and a microwave oscillator **655** unless there is a need to distinguish them from each other.

(42) A frequency of the electromagnetic wave generated by the microwave oscillator **655** is controlled to fall in the frequency range of, desirably, 13.56 MHz or more and 24.125 GHz or less. More desirably, the frequency of the electromagnetic wave is controlled to be a frequency of 2.45 GHz or 5.8 GHz. In this regard, the frequencies of the microwave oscillators **655-1** and **655-2** may be set to be the same or different.

(43) Further, in the present embodiments, two microwave oscillators **655** are arranged on the side surface of the case **102**. However, the present disclosure is not limited thereto. One or more microwave oscillators may be installed and may be arranged on different side surfaces such as opposite side surfaces of the case **102**. An electromagnetic wave supplier (also referred to as an electromagnetic wave supply device, a microwave supplier or a microwave supply device) as a

heater is mainly composed of the microwave oscillators **655-1** and **655-2**, the waveguides **654-1** and **654-2** and the electromagnetic wave introduction ports **653-1** and **653-2**.
(44) A controller **121**, which will be described later, is connected to each of the microwave oscillators **655-1** and **655-2**. The temperature sensor **263** for measuring the temperature of the quartz plate **101***a* or **101***b* or the wafer **200** accommodated in the process chamber **201** is connected to the controller **121**. The temperature sensor **263** measures the temperature of the quartz plate **101** or the wafer **200** by a below-described method and transmits the measured temperature to the controller **121**. The controller **121** controls the outputs of the microwave oscillators **655-1** and **655-2** to control the heating of the wafer **200**. As the method of controlling the heating performed by the heater, it may be possible to use a method of controlling the heating of the wafer **200** by controlling a voltage inputted to the microwave oscillator **655**, a method of controlling the heating of the wafer **200** by changing a ratio of the on-time of the power source of the microwave oscillator **655** and the off-time of the power source thereof, and the like.
(45) The microwave oscillators **655-1** and **655-2** are controlled by the same control signal transmitted from the controller **121**. However, the present disclosure is not limited thereto. The microwave oscillators **655-1** and **655-2** may be configured to be individually controlled by individual control signals transmitted from the controller **121** to the microwave oscillators **655-1** and **655-2**, respectively.
(46) (Cooling Chamber)
(47) As shown in FIGS. **2** and **4**, a cooling chamber (also referred to as a cooling area or a cooler) **204** as a cooling region for cooling the wafer **200** subjected to a predetermined substrate processing is formed by a cooling case **109** on a lateral side of the transfer chamber **203** at a position substantially equidistant from the process chambers **201-1** and **201-2** between the process chambers **201-1** and **201-2**, specifically at a position substantially equidistant from the substrate loading/unloading ports **206** of the process chambers **201-1** and **201-2**. Inside the cooling chamber **204**, there is provided a wafer cooling mounting tool (also referred to as a cooling stage and hereinafter referred to as CS) **108** having a structure similar to that of the boat **217** as a substrate holder. As shown in FIGS. **5**A and **5**B described later, the CS **108** is configured to horizontally hold a plurality of wafers **200** in multiple stages in the vertical direction by a plurality of wafer holding grooves **107***a* to **107***d*. Further, in the cooling case **109**, there is installed a gas supply nozzle (cooling chamber gas supply nozzle) **401** as a cooling chamber purge gas supplier that supplies an inert gas as a purge gas (cooling chamber purge gas) for purging an atmosphere in the cooling chamber **204** via a gas supply pipe (cooling chamber gas supply pipe) **404** at a predetermined first gas flow rate. The gas supply nozzle **401** may be an opening nozzle having an opened nozzle end. It is desirable to use a multi-hole nozzle with a plurality of gas supply holes installed on a side wall of the nozzle facing the CS **108**. Further, a plurality of gas supply nozzles **401** may be installed. The purge gas supplied from the gas supply nozzle **401** may be used as a cooling gas for cooling the processed wafers **200** mounted on the CS **108**.
(48) As shown in FIG. **2**, it is desirable that the cooling chamber **204** is installed between the process chamber **201-1** and the process chamber **201-2**. As a result, the moving distance (moving time) between the process chamber **201-1** and the cooling chamber **204** and the moving distance between the process chamber **201-2** and the cooling chamber **204** can be made the same, and a takt time can be made the same. Further, by installing the cooling chamber **204** between the process chamber **201-1** and the process chamber **201-2**, it is possible to improve the transfer throughput.
(49) As shown in FIGS. **5**A and **5**B, the CS **108** installed inside the cooling chamber **204** is capable of holding four wafers **200**. That is, the CS **108** is configured to be capable of cooling the wafers **200** (four wafers) at least twice the number of wafers **200** (**2** wafers) heated in the process chamber **201-1** or **201-2**.
(50) Further, in the cooling chamber **204**, there are installed an exhaust port **405** for exhausting the cooling chamber purge gas, an opening/closing valve (or APC valve) **406** as a cooling chamber

exhaust valve for adjusting an gas exhaust amount, and an exhaust pipe **407** as a cooling chamber exhaust pipe. In the exhaust pipe **407** at the rear stage of the opening/closing valve **406**, there may be installed a cooling chamber vacuum pump (not shown) for positively exhausting an atmosphere in the cooling chamber **204**. The exhaust pipe **407** may be connected to a purge gas circulation structure for circulating an atmosphere in the transfer chamber **203** which will be described later.
(51) Further, a cooling chamber pressure sensor (cooling chamber pressure gauge) **408** for detecting a pressure in the cooling chamber **204** is installed in the cooling case **109**. In order to keep a difference between a pressure in the transfer chamber detected by a transfer chamber pressure sensor (transfer chamber pressure gauge) **180** and a pressure in the cooling chamber **204** constant, the controller **121** described later controls the MFC **403** as a cooling chamber MFC and the valve **402** as a cooling chamber valve to perform supply or supply stop of the purge gas, and controls the opening/closing valve **406** and the cooling chamber vacuum pump to perform exhaust and exhaust stop of the purge gas. By these controls, the pressure in the cooling chamber **204** and the temperature of the wafers **200** mounted on the CS **108** are controlled. A cooling chamber gas supply system (first gas supplier) is mainly composed of the gas supply nozzle **401**, the valve **402**, the MFC **403**, and the gas supply pipe **404**. A cooling chamber gas exhaust system (cooling chamber gas exhauster) is mainly composed of the exhaust port **405**, the opening/closing valve **406** and the exhaust pipe **407**. The cooling chamber vacuum pump may be included in cooling chamber gas exhaust system. Further, a temperature sensor (not shown) for measuring the temperature of the wafers **200** mounted on the CS **108** may be installed in the cooling chamber **204**. In this specification, each of the wafer holding grooves **107***a* to **107***d* is simply described as a wafer holding groove **107** unless there is a need to distinguish them from each other.
(52) (Drive Mechanism)
(53) The configuration and operation of the drive mechanism **267** will be described with reference to FIGS. **8** to **12**. As shown in FIGS. **9** and **10**, the drive mechanism **267** includes an engaging portion **267***a* fixed to a bottom of the case **102**, an input shaft **267***b* rotated by a driver (not shown), and an output shaft **267***c* having a rotation center RCo that is off-centered from a rotation center RCi of the input shaft **267***b*. A concave portion **268** is formed in an upper portion of the input shaft **267***b*, and gear teeth GTi are formed on an inner circumference of the concave portion **268**. The output shaft **267***c* has gear teeth GTo on an outer circumference thereof. The teeth GTi of the concave portion **268** of the input shaft **267***b* and the teeth GTo of the output shaft **267***c* are fitted with each other and are configured to rotate in opposite directions to each other.
(54) As shown in FIG. **8**, a mounting table **210** is installed on the output shaft **267***c* via a shaft **255** such that a rotation center RCo of the output shaft **267***c* and a rotation center of the mounting table **210** coincide with each other. The rotation center RCb of the boat **217** (wafer **200**) may coincide with or may be off-centered from the rotation center RCo of the output shaft **267***c*. The boat **217**, the output shaft **267***c*, and the input shaft **267***b* constitute a substrate holder.
(55) By setting the rotation center RCo of the output shaft **267***c* to be off-centered with respect to the rotation center RCi of the input shaft **267***b*, the output shaft **267***c* moves along an orbit revolving around the rotation center RCi of the input shaft **267***b*. Further, the rotation number of the output shaft **267***c* for one rotation of the input shaft **267***b* can be determined by a gear ratio between the input shaft **267***b* and the output shaft **267***c*. As a result, the rotation center of the input shaft **167***b* is deviated from the rotation center of the mounting table **210** installed on the output shaft **267***c* via the shaft **255**. Therefore, eccentric rotation is generated, and a relationship of rotation and revolution is established. It is desirable that the rotation number of the output shaft **267***c*, which is the rotation number of the wafer **200**, is an integral multiple of the rotation number of the input shaft **267***b*. By adopting the integral multiple, for example, when the processing is completed, the wafer **200** is returned to an original position (substrate transfer position). This makes it easy to load and unload the wafer **200**.
(56) For example, when a ratio of the rotation number of the input shaft **267***b* to the rotation

number of the output shaft **267**_c_ is 1:2, the wafer **200** moves along an orbit shown in FIG. **11**. In this case, the rotation center RCo of the output shaft **267**_c_ and the rotation center RCb of the wafer **200** coincide with each other. While the wafer **200** rotates in a clockwise direction by one rotation (revolution) in accordance with the rotation of the input shaft **267**_b_, the wafer **200** itself rotates in a counterclockwise direction (rotation). In FIG. **11**, a notch **20** is shown such that the rotation position of the wafer **200** becomes clear.
(57) Further, when a ratio of the rotation number of the input shaft **267**_b_ to the rotation number of the output shaft **267**_c_ is 1:2 and the rotation center RCo of the output shaft **267**_c_ and the rotation center RCb of the wafer **200** are deviated from each other, the wafer **200** moves along an orbit shown in FIG. **12**. The spin (rotation) of the wafer **200** itself does not change, but an orbit of spin (revolution) draws an elliptical orbit.
(58) By changing a gear ratio (rotation number) between the input shaft **267**_b_ and the output shaft **267**_c_ of the drive mechanism **267** as described above, a fixed point of the wafer **200** disappears. This makes it possible to suppress a phenomenon that thick portions and thin portions appear in a circumferential direction by an influence of a standing wave due to wavelength and frequency of an electromagnetic wave in induction heating of irradiating an electromagnetic wave to the wafer **200**. Accordingly, non-uniformity of the film thickness is improved.
(59) (Control Device)
(60) As shown in FIG. **6**, the controller **121**, which is a control part (control device or control means), is configured as a computer that includes a CPU (Central Processing Unit) **121**_a_, a RAM (Random Access Memory) **121**_b_, a memory device **121**_c_, and an I/O port **121**_d_. The RAM **121**_b_, the memory device **121**_c_ and the I/O port **121**_d_ are configured to exchange data with the CPU **121**_a_ via an internal bus **121**_e_. An input/output device **122** configured as, for example, a touch panel or the like is connected to the controller **121**.
(61) The memory device **121**_c_ is composed of, for example, a flash memory, an HDD (Hard Disk Drive), or the like. The memory device **121**_c_ readably stores a control program that controls an operation of a substrate processing apparatus, a process recipe that describes the procedure and conditions of an annealing (modifying) process, and the like. The process recipe is a combination that can allow the controller **121** to execute each procedure in a below-described substrate processing process to obtain a predetermined result. The process recipe functions as a program. Hereinafter, the process recipe, the control program, and the like are collectively and simply referred to as a program. In addition, the process recipe is also simply referred to as a recipe. When the term “program” is used herein, it may include only a recipe, only a control program, or both. The RAM **121**_b_ is configured as a memory area (work area) in which programs, data, and the like read by the CPU **121**_a_ are temporarily held.
(62) The I/O port **121**_d_ is connected to the transfer machine **125**, the MFC **241**, the valve **243**, the pressure sensor **245**, the APC valve **244**, the vacuum pump **246**, the temperature sensor **263**, the drive mechanism **267**, the microwave oscillator **655**, and the like.
(63) The CPU **121**_a_ is configured to read the control program from the memory device **121**_c_ and execute the same. The CPU **121**_a_ is also configured to read the process recipe from the memory device **121**_c_ in response to an input of an operation command from the input/output device **122**. The CPU **121**_a_ is configured to control, according to the contents of the process recipe thus read, a transfer operation of the substrate performed by the transfer machine, a flow rate adjustment operation of various gases performed by the MFC **241**, the opening/closing operation of the valve **243**, a pressure regulation operation performed by the APC valve **244** based on the pressure sensor **245**, start and stop of the vacuum pump **246**, an output adjustment operation of the microwave oscillator **655** based on the temperature sensor **263**, rotation, rotation speed adjustment or elevation operations of the mounting table **210** (or the boat **217**) performed by the drive mechanism **267**, and the like.
(64) The controller **121** may be configured by installing, in a computer, the above-described

program stored in an external memory device (e.g., a magnetic disk such as a hard disk or the like, an optical disk such as a CD or the like, a magneto-optical disk such as an MO or the like, or a semiconductor memory such as a USB memory or the like) **123**. The memory device **121***c* or the external memory device **123** is configured as a non-transitory computer-readable recording medium. Hereinafter, the memory device **121***c* and the external memory device **123** will be generally and simply referred to as a "recording medium." When the term "recording medium" is used herein, it may indicate a case of including only the memory device **121***c*, a case of including only the external memory device **123**, or a case of including both the memory device **121***c* and the external memory device **123**. The provision of the program to the computer may be performed by using a communication means such as the Internet or a dedicated line without using the external memory device **123**.

(65) (2) Substrate Processing Process

(66) Next, as one process of manufacturing a semiconductor device using the process furnace of the above-described substrate processing apparatus **100**, for example, an example of a method of modifying (crystallizing) an amorphous silicon film as a silicon-containing film formed on a substrate will be described with reference to a process flow shown in FIG. **7**. In the following description, operations of respective parts constituting the substrate processing apparatus **100** are controlled by the controller **121**. In the substrate processing process according to the present embodiments, similar to the process furnace structure described above, the same processing contents or the same recipe is used in a plurality of processes. Therefore, the substrate processing process performed using one process furnace will be described, and the description of the substrate processing process performed using the other process furnace will be omitted.

(67) When the term "wafer" is used herein, it may refer to "a wafer itself" or "a stacked body of a wafer and a predetermined layer or film formed on the surface of the wafer." Furthermore, when the phrase "a surface of a wafer" is used herein, it may refer to "a surface of a wafer itself" or "a surface of a predetermined layer or the like formed on a wafer." Moreover, the expression "a predetermined layer is formed on a wafer" as used herein may mean that "a predetermined layer is directly formed on a surface of a wafer itself" or that "a predetermined layer is formed on a layer or the like formed on a wafer." When the term "substrate" or "semiconductor substrate" is used herein, it may be synonymous with the term "wafer."

(68) (Substrate Taking-out Step (S**801**))

(69) As shown in FIG. **1**, the transfer machine **125** takes out a predetermined number of wafers **200** to be processed from the pod **110** opened by the load port unit **106** and loads the wafers **200** on both the tweezers **125***a***-1** and **125***a***-2**. That is, two wafers are placed on the tweezers **125***a***-1** for low temperature and the tweezers **125***a***-2** for high temperature, and the two wafers are taken out from the pod **110**.

(70) (Substrate Loading Step (S**802**))

(71) As shown in FIGS. **1** and **3**, the wafers **200** placed on the tweezers **125***a***-1** and **125***a***-2** are loaded into a predetermined process chamber **201** by opening and closing the gate valve **205** (boat loading). That is, the two wafers placed on the tweezers **125***a***-1** for low temperature and the tweezers **125***a***-2** for high temperature are loaded into the process chamber **201**.

(72) (In-Furnace Pressure Regulation/Temperature Adjustment Step (S**803**))

(73) After the loading of the boat **217** into the process chamber **201** is completed, the atmosphere in the process chamber **201** is controlled such that the pressure in the process chamber **201** becomes a predetermined pressure (for example, 10 to 102,000 Pa). Specifically, while exhausting by the vacuum pump **246**, a valve opening degree of the pressure regulator **244** is feedback-controlled based on pressure information detected by the pressure sensor **245** such that the pressure in the process chamber **201** is set to a predetermined pressure. At the same time, the electromagnetic wave supplier may be controlled to perform pre-heating and may be controlled to perform heating to a predetermined temperature (S**803**). When the temperature is raised to a predetermined

substrate processing temperature by the electromagnetic wave supplier, it is desirable that the temperature raising is performed by an output smaller than an output of a below-described modifying step such that the wafer **200** is not deformed or broken. In the case where a substrate processing process is performed at an atmospheric pressure, after the in-furnace temperature is adjusted without regulating the in-furnace pressure, the process may be controlled so as to proceed to an inert gas supply step S**804** to be described later.

(74) (Inert Gas Supply Step (S**804**))

(75) After the pressure and the temperature in the process chamber **201** are controlled to predetermined values in the in-furnace pressure regulation/temperature adjustment step S**803**, the drive mechanism **267** rotates the shaft **255** and rotates the wafer **200** via the boat **217** on the mounting table **210**. At this time, an inert gas such as a nitrogen gas or the like is supplied through the gas supply pipe **232** (S**804**). Furthermore, at this time, the pressure in the process chamber **201** is regulated to a predetermined value falling within a range of 10 Pa to 102,000 Pa, for example, 101,300 Pa or more and 101,650 Pa or less. Further, the shaft **255** may be rotated during the substrate loading step S**802**, that is, after the wafer **200** has been completely loaded into the process chamber **201**.

(76) (Modifying Step (S**805**))

(77) When the interior of the process chamber **201** is maintained at a predetermined pressure, the microwave oscillator **655** supplies a microwave into the process chamber **201** via the above-described respective parts. By supplying the microwave into the process chamber **201**, the wafer **200** is heated to a temperature of 100 degrees C. or more and 1,000 degrees C. or less, specifically 400 degrees C. or more and 900 degrees C. or less, more specifically 500 degrees C. or more and 700 degrees C. or less. By performing the substrate processing process at such a temperature, the substrate is processed at a temperature at which the wafer **200** efficiently absorbs the microwave. This makes it possible to increase a speed of the modifying step. In other words, if the wafer **200** is processed at a temperature lower than 100 degrees C. or higher than 1,000 degrees C., the surface of the wafer **200** deteriorates and becomes difficult to absorb the microwave. Therefore, it becomes difficult to heat the wafer **200**. Accordingly, it is desirable to perform the substrate processing process within the above-described temperature range.

(78) For example, in the present embodiments in which heating is performed by an electromagnetic wave heating method, a standing wave is generated in the process chamber **201**. On the wafer **200** (also, similar to the wafer **200**, the susceptor **103** in the case where the susceptor **103** is loaded), there are generated a locally-heated concentrated heating region (hot spot) and a remaining unheated region (non-heating region). By controlling an on/off operation of the power supply of the electromagnetic wave supplier in order to suppress deformation of the wafer **200** (also, similar to the wafer **200**, the susceptor **103** in the case where the susceptor **103** is loaded), it is possible to suppress generation of a hot spot on the wafer **200**. At this time, it is possible to suppress deformation of the wafer **200** by controlling the supply power of the electromagnetic wave supplier to a low output and an influence of the hot spot to be decreased. However, in this case, since an energy radiated to the wafer **200** or the susceptor **103** becomes small, the heating temperature also becomes small, and thus it is needed to lengthen the heating time.

(79) As described above, the temperature sensor **263** is a non-contact-type temperature sensor. If deformation, position shift or breakage occurs in the wafer **200** as a measurement target (also the susceptor **103**, similar to the wafer **200**), the position of the wafer **200** monitored by the temperature sensor **263** and the measurement angle with respect to the wafer **200** are changed. Therefore, the measurement value (monitoring value) may become inaccurate and the measurement temperature may be changed rapidly. In the present embodiments, a rapid change in the measurement temperature of the radiation thermometer due to such deformation or breakage of the measurement target is used as a trigger for turning on and off the electromagnetic wave supplier.

(80) By controlling the microwave oscillator **655** as described above, the wafer **200** is heated, and

the amorphous silicon film formed on the surface of the wafer **200** is modified (crystallized) into a polysilicon film (S**805**). That is, it becomes possible to uniformly modify the wafer **200**. In the case where the measured temperature of the wafer **200** becomes high or low beyond the above-mentioned threshold value, the output of the microwave oscillator **655** may be lowered without turning off the microwave oscillator **655**, whereby the temperature of the wafer **200** may be set to fall within a predetermined range. In this case, when the temperature of the wafer **200** returns to the temperature falling within the predetermined range, the output of the microwave oscillator **655** is controlled to become high.
(81) When a preset processing time has elapsed, the rotation of the boat **217**, the supply of the gas, the supply of the microwave and the exhaust through the exhaust pipe are stopped.
(82) (Substrate Unloading Step (S**806**))
(83) After the pressure in the process chamber **201** is returned to the atmospheric pressure, the gate valve **205** is opened to allow the process chamber **201** and the transfer chamber **203** to spatially communicate with each other. Thereafter, one heated (processed) wafer **200** mounted on the boat **217** is unloaded to the transfer chamber **203** by the tweezers **125***a***-2** for high temperature of the transfer machine **125** (S**806**).
(84) (Substrate Cooling Step (S**807**))
(85) The one heated (processed) wafer **200** unloaded by the tweezers **125***a***-2** for high temperature is moved to the cooling chamber **204** by a continuous operation of the transfer device **125***b* and the transfer device elevator **125***c* and is mounted on the CS **108** by the tweezers **125***a***-2** for high temperature. Specifically, as shown in FIG. **5**A, the wafer **200***a* subjected to the modifying step S**805** and held by the tweezers **125***a***-2** for high temperature is transferred to the wafer holding groove **107***b* formed in the CS **108**, and is held for a predetermined time, so that the wafer **200***a* is cooled (S**807**). At this time, when the cooled wafer **200***b* which has already been cooled in the CS **108** is mounted as shown in FIG. **5**B, the tweezers **125***a***-2** for high temperature after mounting the wafer **200***a* subjected to the modifying step S**805** on the wafer holding groove **107***b*, and the tweezers **125***a***-1** for low temperature transfer the two cooled wafers **200***b* to the load port, that is, the pod **110**.
(86) When two wafers **200** are collectively heated (processed) on the boat **217** in the process chamber **201**, the substrate unloading step (S**806**) and the substrate cooling step (S**807**) are continuously performed a plurality of times (twice in this example). Thus, two high-temperature wafers **200***a* are mounted on the CS **108** one by one by the tweezers **125***a***-2** for high temperature. At this time, when two cooled wafers **200***b* are mounted on the CS **108**, the two cooled wafers **200***b* are unloaded from the CS **108** to the pod **110** by the tweezers **125***a***-2** for high temperature and the tweezers **125***a***-1** for low temperature. As a result, it is possible to shorten a time for the tweeters **125***a***-2** for high temperature to hold the high-temperature wafer **200***a*, which makes it possible to reduce a heat load of the transfer machine **125**. In addition, it is possible to prolong a time for cooling the wafer **200**.
(87) As described above, the tweezers **125***a***-2** for high temperature is installed, and the high-temperature wafer **200***a* heated (processed) in the process chamber **201** is moved to the CS **108** in the cooling chamber **204** by the tweezers **125***a***-2** for high temperature while keeping the wafer **200***a* at a relatively high temperature without cooling the wafer **200***a* to, for example, 100 degrees C. or less in the process chamber **201**.
(88) (Substrate Accommodating Step (S**808**))
(89) Two wafers **200** cooled in the substrate cooling step S**807** are taken out from the cooling chamber **204** by the tweezers **125***a***-1** for low temperature and the tweezers **125***a***-2** for high temperature and are transferred to a predetermined pod **110**. By combining the single-wafer transfer (loading into the cooling chamber **204**) and the two-wafer transfer (transfer from the cooling chamber **204**) in this way, it is possible to speed up the transfer of the wafer **200**.
(90) By performing the above operation one or more times, the wafer **200** is modified and moved

to the next substrate processing process. Although there has been described the configuration in which the substrate processing process is performed by mounting two wafers **200** on the boat **217**, the present disclosure is not limited thereto. The wafers **200** may be mounted, one by one, on the boats **217** installed in the process chambers **201-1** and **201-2** and may be subjected to the same process. By performing a swap process, two wafers **200** may be processed in the process chambers **201-1** and **201-2**. At this time, the transfer destination of the wafer **200** may be controlled such that the numbers of times of the substrate processing process performed in the respective process chambers **201-1** and **201-2** are matched with each other. By performing such control, the numbers of times of the substrate processing process performed in the respective process chambers **201-1** and **201-2** become constant, which makes it possible to efficiently perform a work such as maintenance or the like. For example, when the process chamber to which the wafer **200** has been previously transferred is the process chamber **201-1**, control is performed such that the destination of the next wafer **200** becomes the process chamber **201-2**, which makes it possible to control the numbers of times of the substrate processing process executed in the respective process chambers **201-1** and **201-2**.

(91) According to the present embodiments, one or more of the following effects may be obtained.

(92) (a) In the microwave annealing, an electric field distribution is generated by a standing wave. During the rotation of the substrate with the center position thereof fixed, the electric field distribution causes heating unevenness due to a hot spot. Therefore, by changing the rotation center of the substrate, it is possible to reduce uneven heating.

(93) (b) By installing the center of the input shaft of the rotator at a position deviated from the center of the substrate, it is possible to reduce heating unevenness.

(94) (c) The rotation number of the substrate is an integral multiple of the rotation number of the input shaft of the rotator. As a result, when the processing is completed after a predetermined time has elapsed, it is possible to return the substrate to the same position (substrate loading position) as at the start of rotation. This makes it easy to load the substrate into the substrate holder or unload the substrate from the substrate holder.

(95) (d) The input shaft and the output shaft of the rotator have gears, respectively, and the number of gear teeth on the input shaft is integral multiple of the number of gear teeth on the output shaft. As a result, when the processing is completed after a predetermined time has elapsed, it is possible to return the substrate to the same position (substrate loading position) as at the start of rotation. This makes it easy to load the substrate into the substrate holding part or unload the substrate from the substrate holding part.

(96) The configuration of the above-described embodiments may be appropriately modified, and the effects thereof may also be obtained. For example, in the above description, there has been described the process of modifying an amorphous silicon film as a film containing silicon as a main component into a polysilicon. However, the present disclosure is not limited thereto. The film formed on the surface of the wafer **200** may be modified by supplying a gas containing at least one selected from the group of oxygen (O), nitrogen (N), carbon C), and hydrogen (H). For example, in the case where a hafnium oxide film (Hf.sub.xO.sub.y film) as a high dielectric film is formed on the wafer **200**, a microwave may be supplied to heat the hafnium oxide film while supplying a gas containing oxygen. This makes it possible to supplement a lost oxygen in the hafnium oxide film and to improve characteristics of the high dielectric film.

(97) Although the hafnium oxide film is shown herein, the present disclosure is not limited thereto. The present disclosure may be suitably applied to a case of modifying an oxide film containing at least one metal element of aluminum (Al), titanium (Ti), zirconium (Zr), tantalum (Ta), niobium (Nb), lanthanum (La), cerium (Ce), yttrium (Y), barium (Ba), strontium (Sr), calcium (Ca), lead (Pb), molybdenum (Mo), tungsten (W) and the like, i.e., a metal-based oxide film. That is, the aforementioned film-forming sequence may be suitably applied to a case of modifying a TiOCN film, a TiOC film, a TiON film, a TiO film, a ZrOCN film, a ZrOC film, a ZrON film, a ZrO film, a

HfOCN film, a HfOC film, a HfON film, a HfO film, a TaOCN film, a TaOC film, a TaON film, a TaO film, a NbOCN film, a NbOC film, a NbON film, a NbO film, an AlOCN film, an AlOC film, an AlON film, an AlO film, a MoOCN film, a MoOC film, a MoON film, a MoO film, a WOCN film, a WOC film, a WON film or a WO film, which is formed on the wafer **200**.

(98) In addition to the high dielectric film, a film doped with impurities and containing silicon as a main component may be heated. Examples of the film containing silicon as a main component include Si-based oxide films such as a silicon nitride film (SiN film), a silicon oxide film (SiO film), a silicon oxycarbide film (SiOC film), a silicon oxycarbonitride film (SiOCN film), a silicon oxynitride film (SiON film), and the like. Examples of the impurities include at least one selected from the group of boron (B), carbon (C), nitrogen (N), aluminum (Al), phosphorus (P), gallium (Ga), arsenic (As), and the like.

(99) Furthermore, the film may be a resist film based on at least one selected from the group of a polymethyl methacrylate (PMMA) resin, an epoxy resin, a novolac resin, a polyvinyl phenyl resin, and the like.

(100) Although one process of manufacturing a semiconductor device has been described above, the present disclosure is not limited thereto but may be applied to a substrate processing technique such as a patterning process of a liquid crystal panel manufacturing process, a patterning process of a solar cell manufacturing process, a patterning process of a power device manufacturing process, or the like.

(101) The present disclosure is not limited to the above-described embodiments and includes various modifications. For example, the above embodiments have been described in detail for a better understanding of the present disclosure and is not needed to be limited to the one including all the configurations described above.

(102) Further, there has been described an example of creating a program that realizes a part or all of the above-mentioned configurations, functions, control devices and the like. Needless to say, all or part of them may be realized as hardware by, for example, them in an integrated circuit. That is, all or part of the functions of the processing part may be realized by, for example, an integrated circuit such as an ASIC (Application Specific Integrated Circuit) or an FPGA (Field Programmable Gate Array) instead of the program.

(103) According to the present disclosure in some embodiments, it is possible to improve the film thickness uniformity.

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

Claims

1. A substrate processing apparatus, comprising: a process chamber configured to process at least one substrate; a microwave generator configured to generate a microwave; a substrate holder configured to load and hold the at least one substrate; and a rotator which includes an output shaft configured to support the substrate holder and an input shaft installed at an off-centered position with respect to the output shaft, wherein a concave portion is formed in an upper portion of the input shaft and first gear teeth are formed on an inner circumference of the concave portion, wherein second gear teeth are formed on an outer circumference of the output shaft, and wherein the first gear teeth of the concave portion of the input shaft are fitted with the second gear teeth of the output shaft.

2. The substrate processing apparatus of claim 1, wherein the output shaft is off-centered with respect to a center of the at least one substrate.
3. The substrate processing apparatus of claim 1, wherein the input shaft and the output shaft are fitted to each other, and the input shaft and the output shaft are configured to rotate in opposite directions.
4. The substrate processing apparatus of claim 1, wherein a rotation number of the input shaft and a rotation number of the output shaft are different from each other.
5. The substrate processing apparatus of claim 1, wherein a rotation number of the output shaft is an integral multiple of a rotation number of the input shaft.
6. The substrate processing apparatus of claim 1, wherein a rotation number of the at least one substrate is an integral multiple of a rotation number of the input shaft.
7. A substrate holding apparatus, comprising: a substrate holder configured to load and hold at least one substrate; an output shaft configured to support the substrate holder; and an input shaft installed at an off-centered position with respect to the output shaft, wherein a concave portion is formed in an upper portion of the input shaft and first gear teeth are formed on an inner circumference of the concave portion, wherein second gear teeth are formed on an outer circumference of the output shaft, and wherein the first gear teeth of the concave portion of the input shaft are fitted with the second gear teeth of the output shaft.
8. The substrate holding apparatus of claim 7, wherein the output shaft is off-centered with respect to a center of the at least one substrate.
9. The substrate holding apparatus of claim 7, wherein the input shaft and the output shaft are fitted to each other, and the input shaft and the output shaft are configured to rotate in opposite directions.
10. The substrate holding apparatus of claim 7, wherein a rotation number of the input shaft and a rotation number of the output shaft are different from each other.
11. The substrate holding apparatus of claim 7, wherein a rotation number of the output shaft is an integral multiple of a rotation number of the input shaft.
12. The substrate holding apparatus of claim 7, wherein a rotation number of the at least one substrate is an integral multiple of a rotation number of the input shaft.
13. A method of manufacturing a semiconductor device, comprising: loading at least one substrate into a substrate processing apparatus that includes a process chamber configured to process the at least one substrate, a microwave generator configured to generate a microwave, a substrate holder configured to load and hold the at least one substrate, and a rotator which includes an output shaft configured to support the substrate holder and an input shaft installed at an off-centered position with respect to the output shaft; and heating the at least one substrate with the microwave, wherein a concave portion is formed in an upper portion of the input shaft and first gear teeth are formed on an inner circumference of the concave portion, wherein second gear teeth are formed on an outer circumference of the output shaft, and wherein the first gear teeth of the concave portion of the input shaft are fitted with the second gear teeth of the output shaft.