[DESCRIPTION]

[Title]

SUBSTRATE PROCESSING DEVICE, METHOD FOR MANUFACTURING SEMICONDUCTOR DEVICE, AND SIGN DETECTION PROGRAM

[Technical Field]

[0001]

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

[Related Art]

[0002]

In general, a substrate processing apparatus capable of manufacturing a semiconductor device by forming a film on a substrate such as a wafer may be constituted by various components such as a vacuum pump configured to exhaust (vacuum-exhaust) a process chamber, a mass flow controller configured to control a flow rate of a gas such as a reactive gas, an opening/closing valve, a pressure gauge, a heater configured to heat the process chamber, and a transfer structure configured to transfer a component such as the substrate.

[0003]

Since a component among the various components described above may gradually deteriorate with use to fall into failure, it is necessary to replace the component with a new component. Depending on a replacement method of the component, the component may be used until it fails, or the component may be regularly replaced with the new component well before it fails by performing a regular replacement cycle for the component. However, when the component is used until it fails, the entirety of the substrate processed by the substrate processing apparatus at the time of failure may become defective, and the substrate and a production time at the time of failure may be lost. In addition, when the component is regularly replaced with the new component before it fails,

the component is replaced with the new component every short period even though the component does not fail within that period. Therefore, a replacement frequency of the component may increase, which may lead to an increase in an operating cost.

[0004]

Further, as in Patent Document 1 or Patent Document 2, various techniques of maintaining the components have been proposed. However, it may not be possible to detect an abnormality of each component in advance even with the various techniques.

[Related Art Document]

[Patent document]

[0005]

Patent Document 1: International Patent Publication No. WO2016/157402

Patent Document 2: International Patent Publication No. WO2017/158682

[Disclosure]

[Technical Problem]

[0006]

It is an object of the present disclosure to provide a technique capable of detecting an abnormal sign of a component.

[Technical Solution]

[0007]

According to an embodiment of the present disclosure, there is provided a configuration of creating a normal model by acquiring sensor data related to a component subject to an abnormal sign detection and monitoring an apparatus state based on the normal model, wherein the sensor data is acquired after a replacement or a maintenance of the component subject to the abnormal sign detection to re-create the normal model by using the sensor data, and an abnormal sign is detected before an abnormal apparatus stop occurs by monitoring the apparatus state based on the normal

model.

[Advantageous Effects]

[0008]

According to some embodiments of the present disclosure, it is possible to provide a technique capable of detecting an abnormal sign of a component.

[Brief Description of Drawings]

[0009]

FIG. 1 is a perspective view schematically illustrating a configuration of a substrate processing apparatus according to an embodiment.

FIG. 2 is a diagram schematically illustrating a vertical cross-section of a process furnace of the substrate processing apparatus according to the embodiment.

FIG. 3 is a block diagram schematically illustrating a configuration of a main controller of the substrate processing apparatus according to the embodiment.

FIG. 4 is a flow chart schematically illustrating a substrate processing when the substrate processing apparatus according to the embodiment is used as a semiconductor manufacturing apparatus.

FIG. 5 is a block diagram schematically illustrating a control system of the substrate processing apparatus according to the embodiment.

FIG. 6 is a diagram for explaining a singular spectrum transformation in the control system of the substrate processing apparatus according to the embodiment.

FIG. 7 is a flow chart schematically illustrating a part of a sign detection process according to a specific example of a third embodiment.

FIG. 8 is a flow chart schematically illustrating a part of a sign detection process according to a specific example of a fourth embodiment.

[Detailed Description]

[0010]

Hereinafter, a method of manufacturing a semiconductor device, a sign detection program and a substrate processing apparatus according to embodiments of the present disclosure will be described. In addition, in FIG. 1, a direction indicated by an arrow F represents a front direction of the substrate processing apparatus, a direction indicated by an arrow B represents a rear direction, a direction indicated by an arrow R represents a right direction a direction indicated by an arrow L represents a left direction, a direction indicated by an arrow U represents an upper direction, and a direction indicated by an arrow D represents a lower direction.

[0011]

<Overall Configuration of Processing Apparatus>

A configuration of a substrate processing apparatus 10 will be described with reference to FIGS. 1 and 2. As shown in FIG. 1, the substrate processing apparatus 10 includes a housing 12 constituted by a pressure resistant vessel. An opening is provided at a front wall of the housing 12 such that a maintenance operation can be performed through the opening, and a pair of front maintenance doors 14 serving as an opening/closing structure configured to open or close the opening are provided at the opening. Further, in the substrate processing apparatus 10, a pod (substrate container) 18 capable of accommodating a substrate (wafer) 16 (see FIG. 2) such as a silicon wafer described later is used as a carrier to transfer the substrate 16 into and out of the housing 12.

[0012]

A pod loading/unloading port is provided at the front wall of the housing 12 so as to communicate between an inside and an outside of the housing 12. A loading port shelf 20 is provided at the pod loading/unloading port. The pod 18 may be placed on the loading port shelf 20. The loading port shelf 20 is configured such that the pod 18 can be placed on the loading port shelf 20 and can be aligned while placed on the loading port shelf 20.

[0013]

A rotatable pod shelf 22 is provided in the housing 12 to be located over a substantially center portion of the housing 12. The rotatable pod shelf 22 is configured such that a plurality of pods 18 can be stored on the rotatable pod shelf 22. The rotatable pod shelf 22 includes a vertical column capable of rotating horizontally and a plurality of shelf plates radially supported by the vertical column at an upper end portion, a mid portion and a lower end portion of the vertical column.

[0014]

A pod transfer device 24 is provided between the loading port shelf 20 and the rotatable pod shelf 22 in the housing 12. The pod transfer device 24 may include: a pod elevator 24A capable of elevating and lowering while supporting the pod 18; and a pod transfer structure 24B. The pod transfer device 24 is configured to transfer the pod 18 among the loading port shelf 20, the rotatable pod shelf 22 and a pod opener 26 described later by consecutive operations of the pod elevator 24A and the pod transfer structure 24B.

[0015]

A sub-housing 28 is provided in the housing 12 at a lower portion of the housing 12 from the substantially center portion to a rear end of the housing 12. A pair of pod openers 26 is provided at a front wall of the sub-housing 28. The substrate 16 may be transferred into or out of the sub-housing 28 through the pair of the pod openers 26.

[0016]

The pod opener 26 includes: a placement table on which the pod 18 is placed; and a cap attaching/detaching structure 30 configured to attach or detach a cap of the pod 18. By detaching or attaching the cap of the pod 18 placed on the placement table by the cap attaching/detaching structure 30 of the pod opener 26, a wafer entrance of the pod 18 may be opened or closed.

[0017]

A transfer chamber 32 fluidically isolated from a space in which components such as the pod transfer device 24 and the rotatable pod shelf 22 are provided is provided in the sub-housing 28. A substrate transfer structure 34 is provided in a front region of the transfer chamber 32. The substrate transfer structure 34 may be constituted by a substrate transfer device 34A and a substrate transfer device elevator 34B. The substrate transfer device 34A is configured to rotate or move the substrate 16 horizontally, and the substrate transfer device elevator 34B is configured to elevate or lower the substrate transfer device 34A.

[0018]

The substrate transfer device elevator 34B is installed between a right end of the front region of the transfer chamber 32 of the sub-housing 28 and a right end of the housing 12. The substrate transfer device 34A may include tweezers (not shown) serving as a holder of the substrate 16. The substrate transfer structure 34 is configured such that the substrate 16 can be loaded (charged) into or unloaded (discharged) out of a boat 36 serving as a substrate retainer by consecutive operations of the substrate transfer device elevator 34B and the substrate transfer device 34A.

[0019]

As shown in FIG. 2, a boat elevator 38 capable of elevating or lowering the boat 36 is provided in the sub-housing 28 (that is, in the transfer chamber 32). An arm 40 is connected to an elevating table of the boat elevator 38. A lid 42 is provided horizontally at the arm 40. The lid 42 is configured to vertically support the boat 36 and to close a lower end of a process furnace 44 described later.

[0020]

A transfer structure configured to transfer the substrate 16 is constituted mainly by components shown in FIG. 1 such as the rotatable pod shelf 22, the pod transfer device 24, the substrate transfer structure 34 and the boat 36 and components shown in FIG. 2 such as the boat elevator 38 and a rotator 46 described later.

[0021]

As shown in FIG. 1, the process furnace 44 is provided above a standby space 50 where the boat 36 is accommodated and in standby. Further, a clean air supply structure 52 is provided at a left side end of the transfer chamber 32, wherein the left side end is located opposite to the substrate transfer device elevator 34B. The clean air supply structure 52 is configured to supply clean air 52A such as a clean atmosphere and an inert gas.

[0022]

Further, a plurality of apparatus covers (not shown) serving as an entrance structure of the substrate processing apparatus 10 is provided on outer circumferences of the housing 12 and the sub-housing 28. Door switches 54 (a door switch 54 of the housing 12 alone is shown) serving as access sensors are provided at end portions of the housing 12 and the sub-housing 28 facing the plurality of apparatus covers, respectively.

[0023]

In addition, a substrate detection sensor 56 configured to detect whether the pod 18 is placed on the loading port shelf 20 is provided at the loading port shelf 20. Switches such as the door switches 54 and sensors such as the substrate detection sensor 56 are electrically connected to a controller 58 for the substrate processing apparatus 10 (see FIGS. 2 and 3) serving as a main controller described later.

[0024]

As shown in FIG. 2, the substrate processing apparatus 10 includes a gas supply structure 60 and an exhaust structure 62 in addition to the housing 12. A process gas supply system and a purge gas supply system are accommodated in the gas supply structure 60. The process gas supply system includes a process gas supply source (not shown), an opening/closing valve (not shown), a mass flow controller (hereinafter, abbreviated as an “MFC”) 64A serving as a gas flow rate controller and a process gas supply pipe 66A. In addition, the purge gas supply system includes a purge gas supply

source (not shown), an opening/closing valve (not shown), an MFC 64B and a purge gas supply pipe 66B.

[0025]

A gas exhaust structure constituted by an exhaust pipe 68, a pressure sensor 70 serving as a pressure detector and a pressure regulator 72 including, for example, an APC (Automatic Pressure Controller) valve is accommodated in the exhaust structure 62. Although not shown, a vacuum pump 74 serving as an exhauster is connected to the exhaust pipe 68 on a downstream side of the exhaust structure 62. The gas exhaust structure may further include the vacuum pump 74.

[0026]

As shown in FIG. 2, the substrate processing apparatus controller 58 serving as the main controller is connected to each of a transfer controller 48, a temperature controller 76, a pressure controller 78 and a gas supply controller 80. In addition, as shown in FIG. 5, the substrate processing apparatus controller 58 is connected to a sign detection controller 82 serving as a sign detector described later.

[0027]

<Configuration of Process Furnace>

As shown in FIG. 2, the process furnace 44 includes a reaction tube (which is a process tube) 84. The reaction tube 84 includes an inner reaction tube (which is an inner tube) 84A and an outer reaction tube (which is an outer tube) 84B provided outside the inner reaction tube 84A. The inner reaction tube 84A is of a cylindrical shape with open upper and lower ends. A process chamber 86 in which the substrate 16 is processed is provided in a hollow portion of the inner reaction tube 84A. The process chamber 86 is configured to accommodate the boat 36.

[0028]

A heater 88 of a cylindrical shape is provided outside the reaction tube 84 to surround a side wall of the reaction tube 84. The heater 88 is vertically supported by a heater base 90.

[0029]

A furnace opening portion (which is a manifold) 92 of a cylindrical shape is provided under the outer reaction tube 84B. The outer reaction tube 84B and the furnace opening portion 92 are concentrically arranged. The furnace opening portion 92 is provided to support a lower end of the inner reaction tube 84A and a lower end of the outer reaction tube 84B. The furnace opening portion 92 engages with the lower end of the inner reaction tube 84A and the lower end of the outer reaction tube 84B.

[0030]

An O-ring 94 serving as a seal is provided between the furnace opening portion 92 and the outer reaction tube 84B. By supporting the furnace opening portion 92 on the heater base 90, the reaction tube 84 is vertically provided. A reaction vessel is constituted by the reaction tube 84 and the furnace opening portion 92.

[0031]

A process gas nozzle 96A and a purge gas nozzle 96B are connected to the furnace opening portion 92 to communicate with the process chamber 86. The process gas supply pipe 66A is connected to the process gas nozzle 96A. Components such as the process gas supply source (not shown) are connected to an upstream side of the process gas supply pipe 66A through the MFC 64A. The purge gas supply pipe 66B is connected to the purge gas nozzle 96B. Components such as the purge gas supply source (not shown) are connected to an upstream side of the purge gas supply pipe 66B through the MFC 64B.

[0032]

The exhaust pipe 68 configured to exhaust an inner atmosphere of the process chamber 86 is connected to the furnace opening portion 92. The exhaust pipe 68 is disposed at a lower end of a cylindrical space 98 which is a gap between the inner reaction tube 84A and the outer reaction tube 84B to communicate with the cylindrical space 98. The pressure sensor 70, the pressure regulator 72

and the vacuum pump 74 are connected to a downstream side of the exhaust pipe 68 in this order from an upstream side of the exhaust pipe 68.

[0033]

The lid 42 of a disk shape capable of sealing a lower end opening of the furnace opening portion 92 in an airtight manner is provided under the furnace opening portion 92. An O-ring 100, serving as a seal and being in contact with a lower end of the furnace opening portion 92, is provided on an upper surface of the lid 42.

[0034]

The rotator 46 configured to rotate the boat 36 is provided about a center of the lid 42 opposite to the process chamber 86. A rotating shaft 102 of the rotator 46 is connected to the boat 36 through the lid 42 and supports the boat 36 from thereunder. Further, the rotator 46 is embedded with a rotary motor 46A. As the rotary motor 46A rotates the rotating shaft 102 of the rotator 46 and the boat 36, the substrate 16 is rotated.

[0035]

The lid 42 can be elevated or lowered in the vertical direction by the boat elevator 38 installed outside the reaction tube 84. When the lid 42 is elevated or lowered by the boat elevator 38, the boat 36 can be loaded into or unloaded out of the process chamber 86. The transfer controller 48 is electrically connected to the rotary motor 46A of the rotator 46 and the boat elevator 38.

[0036]

The boat 36 is configured to accommodate (or support) a plurality of substrates 16 while the plurality of substrates are horizontally oriented with their centers aligned with each other in a multistage manner. In addition, a plurality of insulation plates 104 horizontally oriented are provided under the boat 36 in a multistage manner. The insulation plate 104 serves as a heat insulator and is of a disk shape. For example, each of the boat 36 and the insulation plate 104 is made of a heat resistant material such as quartz and silicon carbide. The insulation plate 104 is provided so as to suppress the

transmission of the heat from the heater 88 to the furnace opening portion 92.

[0037]

In addition, a temperature sensor 106 serving as a temperature detector is provided in the reaction tube 84. The temperature controller 76 is electrically connected to the heater 88 and the temperature sensor 106.

[0038]

<Operation of Substrate Processing Apparatus>

Hereinafter, a method of forming a film on the substrate 16, which is a part of a manufacturing process of a semiconductor device, will be described with reference to FIGS. 1 and 2. In addition, the substrate processing apparatus controller 58 is configured to control operations of components constituting the substrate processing apparatus 10.

[0039]

As shown in FIG. 1, when the pod 18 is placed on the loading port shelf 20 by an in-step transfer apparatus (not shown), the pod 18 is detected by the substrate detection sensor 56 and the pod loading/unloading port (not shown) is opened by a front shutter (not shown). Then, the pod 18 placed on the loading port shelf 20 is transferred into the housing 12 through the pod loading/unloading port by the pod transfer device 24.

[0040]

The pod 18 transferred into the housing 12 is automatically transferred to and temporarily stored in a shelf plate of the rotatable pod shelf 22 by the pod transfer device 24. Thereafter, the pod 18 is transferred to the placement table of one of the pod openers 26 from the shelf plate of the rotatable pod shelf 22. Alternatively, the pod 18 transferred into the housing 12 may be directly transferred and placed onto the placement table of the one of the pod openers 26 by the pod transfer device 24.

[0041]

By detaching the cap of the pod 18 on the placement table by the cap attaching/detaching structure 30, the wafer entrance is opened. Thereafter, the substrate 16 (see FIG. 2) is transported out of the pod 18 by the tweezers of the substrate transfer device 34A via the wafer entrance, aligned by a notch alignment device (not shown), and charged into the standby space 50 provided at a rear portion of the transfer chamber 32. The substrate 16 is then charged (transferred) into the boat 36. Thereafter, the substrate transfer device 34A then returns to the placement table with the pod 18 placed thereon, transports a next substrate 16 from the pod 18, and charges the next substrate into the boat 36.

[0042]

While the substrate transfer structure 34 loads the substrates 16 from the one of the pod openers (that is, one of an upper pod opener and a lower pod opener) 26 into the boat 36, another pod 18 is transferred to and placed on the placement table of the other one of the pod openers (that is, the other one of an upper pod opener and the lower pod opener) 26 from the rotatable pod shelf 22 by the pod transfer device 24. By transferring the another pod 18 to the placement table, an opening operation of each of the pods 18 by each of the pod openers 26 can be simultaneously performed.

[0043]

After a predetermined number of the substrates 16 are charged into the boat 36, the lower end of the process furnace 44 is opened by a furnace opening shutter (not shown). Subsequently, the boat 36 charged with the predetermined number of the substrates 16 is transferred (loaded) into the process furnace 44 by elevating the lid 42 by the boat elevator 38.

[0044]

After the boat 36 accommodating the plurality of the substrates 16 is transferred (loaded) into the process chamber 86 of the process furnace 44 as described above, the lid 42 seals the lower end of the furnace opening portion 92 via the O-ring 100 as shown in FIG. 2.

[0045]

Thereafter, the process chamber 86 is vacuum-exhausted by the vacuum pump 74 such that an inner pressure of the process chamber 86 reaches and is maintained at a predetermined pressure (vacuum degree). While the process chamber 86 is vacuum-exhausted, the pressure regulator 72 (specifically, an opening degree of a valve of the pressure regulator 72) is feedback-controlled based on a pressure value measured by the pressure sensor 70. In addition, the heater 88 heats the process chamber 86 such that an inner temperature of the process chamber 86 reaches and is maintained at a desired temperature. While the heater 88 heats the process chamber 86, the state of the electric conduction to the heater 88 is feedback-controlled based on a temperature value detected by the temperature sensor 106. Subsequently, the boat 36 with the substrates 16 charged therein is rotated by the rotator 46.

[0046]

Subsequently, a process gas is supplied from the process gas supply source, and the process gas whose flow rate is adjusted by the MFC 64A is supplied into the process chamber 86 through the process gas supply pipe 66A and the process gas nozzle 96A. The process gas supplied into the process chamber 86 flows upward in the process chamber 86 and flows into the cylindrical space 98 through an opening at an upper end of the inner reaction tube 84A and is exhausted through the exhaust pipe 68. The process gas contacts a surface of the substrate 16 as it passes through the process chamber 86, whereby a film is deposited on the surface of the substrate 16 by a thermal reaction.

[0047]

After a predetermined process time has elapsed, a purge gas is supplied from the purge gas supply source (not shown), and the purge gas whose flow rate is adjusted by the MFC 64B is supplied into the process chamber 86. The inner atmosphere of the process chamber 86 is replaced with the inert gas, and the inner pressure of the process chamber 86 is returned to a normal pressure.

[0048]

Thereafter, the lower end of the furnace opening portion 92 is opened by lowering the lid 42 by the boat elevator 38. Then, the substrates 16 on which the process is completed are transferred (unloaded) out of the reaction tube 84 through the lower end of the furnace opening portion 92 while being supported by the boat 36. The substrates 16 on which the process is completed are then transferred (discharged) out of the boat 36 and stored in the pod 18.

[0049]

After the substrates 16 on which the process is completed are discharged, the pod 18 accommodating the substrates 16 on which the process is completed is unloaded out of the housing 12 in an order substantially opposite to that described above except for an aligning process of the substrates 16 by the notch alignment device (not shown).

[0050]

<Configuration of Substrate Processing Apparatus Controller>

Hereinafter, the substrate processing apparatus controller 58 serving as the main controller will be described in detail with reference to FIG. 3.

[0051]

The substrate processing apparatus controller 58 is constituted mainly by: an arithmetic controller 108 such as a CPU (Central Processing Unit); a memory 114 such as a RAM 110, a ROM 112 and a hard disk drive (HDD) (not shown); an input device 116 such as a mouse and a keyboard; and a display 118 such as a monitor. In addition, data can be set by each of the arithmetic controller 108, the memory 114, the input device 116 and the display 118.

[0052]

The arithmetic controller 108 constitutes a backbone of the substrate processing apparatus controller 58. The arithmetic controller 108 is configured to execute a control program stored in the ROM 112 and a recipe (for example, a process recipe serving as a substrate processing recipe) stored in the memory 114 functioning as a recipe memory in accordance with an instruction from the input

device 116.

[0053]

The ROM 112 is a recording medium constituted by a component such as a flash memory and a hard disk, and stores data such as an operation program of the arithmetic controller 108 configured to control the operations of the components (for example, the vacuum pump 74) constituting the substrate processing apparatus 10. Further, the RAM 110 (that is, a memory) functions as a temporary memory (that is, a work area) of the arithmetic controller 108.

[0054]

In the present specification, the substrate processing recipe (process recipe) refers to a recipe in which information such as processing conditions and processing sequences of processing the substrate 16 is stored. In addition, data such as a pre-set value or a transmission timing to be transmitted to components such as the transfer controller 48, the temperature controller 76, the pressure controller 78 and the gas supply controller 80 may be stored in a recipe file for each step of the substrate processing recipe.

[0055]

The arithmetic controller 108 is configured to control an inner temperature and an inner pressure of the process furnace 44, a flow rate of the process gas supplied into the process furnace 44 and the like in order to perform a predetermined process to the substrate 16 loaded in the process furnace 44.

[0056]

The transfer controller 48 is configured to control transport operations of the rotatable pod shelf 22, the boat elevator 38, the pod transfer device 24, the substrate transfer structure 34, the boat 36 and the rotator 46, which constitute the transfer structure configured to transfer the substrate 16.

[0057]

Sensors are embedded in the rotatable pod shelf 22, the boat elevator 38, the pod transfer

device 24, the substrate transfer structure 34, the boat 36 and the rotator 46, respectively. The transfer controller 48 is configured to notify the substrate processing apparatus controller 58 of values detected by the sensors when a predetermined value or an abnormal value is detected by the sensors. In addition, a system of detecting an abnormal sign of each component of the substrate processing apparatus 10 will be described in detail later.

[0058]

A data storage region 120 where various data are stored and a program storage region 122 where various programs such as the substrate processing recipe are stored are provided in the memory 114. Various parameters related to the recipe file are stored in the data storage region 120. The various programs such as the substrate processing recipe used for controlling the apparatus are stored in the program storage region 122.

[0059]

A touch panel (not shown) is provided in the display 118 of the substrate processing apparatus controller 58. The touch panel is configured to display an operation screen through which an operation command for a substrate processing system and a substrate transfer system described above is received. In addition, the substrate processing apparatus controller 58 may preferably include at least the display 118 and the input device 116 as an operating terminal (terminal device) such as a personal computer and a mobile terminal.

[0060]

The temperature controller 76 is configured to adjust the inner temperature of the process furnace 44 by controlling a temperature of the heater 88 of the process furnace 44. The temperature controller 76 is also configured to notify the substrate processing apparatus controller 58 of values detected by the temperature sensor 106 when a predetermined value or an abnormal value is detected by the temperature sensor 106.

[0061]

The pressure controller 78 is configured to control the pressure regulator 72 based on the pressure value detected by the pressure sensor 70 such that the inner pressure of the process chamber 86 is at a desired pressure at a desired timing. The pressure controller 78 is also configured to notify the substrate processing apparatus controller 58 of the value detected by the pressure sensor 70 when a predetermined value or an abnormal value is detected by the pressure sensor 70.

[0062]

The gas supply controller 80 is configured to control the MFCs 64A and 64B such that the flow rate of the gas supplied into the process chamber 86 is at a desired flow rate at a desired timing. The gas supply controller 80 is also configured to notify the substrate processing apparatus controller 58 of values detected by a sensor (not shown) provided at components such as the MFCs 64A and 64B when a predetermined value or an abnormal value is detected by the sensor.

[0063]

<Substrate Processing>

Subsequently, a substrate processing of processing the substrate 16 using the substrate processing apparatus 10 serving as a semiconductor manufacturing apparatus will be described with reference to FIG. 4. The substrate processing is a part of a method of manufacturing a semiconductor device such as an IC and an LSI. In the description below, the substrate processing apparatus controller 58 controls the processes and the operations of the components constituting the substrate processing apparatus 10.

[0064]

In the description below, an example of forming a film on the substrate 16 by alternately supplying a source gas (first process gas) and a reactive gas (second process gas) to the substrate 16 will be described. Specifically, an example in which a silicon nitride film (SiN film) serving as a film is formed on the substrate 16 using hexachlorodisilane (Si_2Cl_6, hereinafter, abbreviated as HCDS) gas serving as the source gas and ammonia (NH_3) serving as the reactive gas will be described. A

predetermined film may be formed on the substrate 16 in advance. Further, a predetermined pattern may be formed on the substrate 16 or on the predetermined film in advance.

[0065]

<Substrate Loading Step S102>

First, in the substrate loading step S102, the substrate 16 is transferred into the boat 36, and the boat 36 charged with the substrate 16 is then loaded into the process chamber 86.

[0066]

<Film-Forming Step S104>

In the film-forming step S104, four steps described below are sequentially performed to form the film on the surface of the substrate 16. Further, while performing the first through the fourth steps, the substrate 16 is heated to a predetermined temperature by the heater 88.

[0067]

<First Step>

In the first step, the opening/closing valve (not shown) provided at the process gas supply pipe 66A and the pressure regulator 72 (that is, the APC valve) provided at the exhaust pipe 68 are opened, and the HCDS gas whose flow rate adjusted by the MFC 64A is supplied to the process gas supply pipe 66A to pass through the process gas supply pipe 66A. Then, the HCDS gas is supplied to the process chamber 86 through the process gas nozzle 96A, and exhausted through the exhaust pipe 68. When supplying the HCDS gas, the inner pressure of the process chamber 86 is maintained at a predetermined pressure. As a result, a silicon film (Si film) is formed on the surface of the substrate 16.

[0068]

<Second Step>

In the second step, the opening/closing valve provided at the process gas supply pipe 66A is closed to stop a supply of the HCDS gas. With the pressure regulator 72 (that is, the APC valve)

provided at the exhaust pipe 68 open, the process chamber 86 is exhausted by the vacuum pump 74 to remove the gas remaining in the process chamber 86 from the process chamber 86. In addition, the opening/closing valve provided at the purge gas supply pipe 66B is opened to supply the inert gas such as N_2 gas into the process chamber 86 to purge the process chamber 86, and the gas remaining in the process chamber 86 is discharged (removed) from the process chamber 86 to an outside of the process chamber 86.

[0069]

<Third Step>

In the third step, the opening/closing valve (not shown) provided at the purge gas supply pipe 66B and the pressure regulator 72 (that is, the APC valve) provided at the exhaust pipe 68 are opened, and the NH_3 gas whose flow rate adjusted by the MFC 64B is supplied to the purge gas supply pipe 66B to pass through the purge gas supply pipe 66B. Then, the NH_3 gas is supplied to the process chamber 86 through the purge gas nozzle 96B, and exhausted through the exhaust pipe 68. When supplying the NH_3 gas, the inner pressure of the process chamber 86 is maintained at a predetermined pressure. Thereby, the Si film formed on the surface of the substrate 16 by the HCDS gas reacts with the NH_3 gas. As a result, the silicon nitride film (SiN film) is formed on the surface of the substrate 16.

[0070]

<Fourth Step>

In the fourth step, the opening/closing valve provided at the purge gas supply pipe 66B is closed to stop a supply of the NH_3 gas. With the pressure regulator 72 (that is, the APC valve) provided at the exhaust pipe 68 open, the process chamber 86 is exhausted by the vacuum pump 74 to remove the gas remaining in the process chamber 86 from the process chamber 86. In addition, the inert gas such as N_2 gas is supplied into the process chamber 86 to purge the process chamber 86 again.

[0071]

The SiN film of a predetermined thickness is formed on the substrate 16 by repeatedly performing a cycle including the first step through the fourth step a plurality of times.

[0072]

<Substrate Unloading Step S106>

In the substrate unloading step S106, the boat 36 accommodating the substrate 16 with the SiN film formed thereon is unloaded out of the process chamber 86.

[0073]

<Control System According to Present Embodiments>

Subsequently, a control system of detecting the abnormal sign (a failure sign) of each component of the substrate processing apparatus 10 will be described with reference to FIGS. 5 and 6. In addition, hereinafter, the control system will be described using the example of forming the film on the substrate 16 by the substrate processing apparatus 10.

[0074]

As shown in FIG. 5, the control system includes the substrate processing apparatus controller 58 serving as the main controller, the sign detection controller 82 serving as the sign detector, various sensors 124, a data collection unit (hereinafter, abbreviated as a “DCU”) 126 and an edge controller (hereinafter, abbreviated as an “EC”) 128, and each component of the control system is connected by wire or wirelessly.

[0075]

The substrate processing apparatus controller 58 is connected to a host computer (not shown) such as a customer host computer and an operation device (not shown). The operation device is configured to be capable of exchanging various data such as sensor data acquired by the substrate processing apparatus controller 58 with the host computer.

[0076]

The sign detection controller 82 is configured to acquire the sensor data from the sensor of each component provided in the substrate processing apparatus 10 and further configured to monitor a state of the substrate processing apparatus 10. Specifically, the sign detection controller 82 calculates a numerical index using the data from the various sensors 124, and detects the abnormal sign by comparing the numerical index with a predetermined threshold value. In addition, the sign detection controller 82 is embedded with a sign detection program configured to detect the abnormal sign based on a temporal behavior of the sensor data.

[0077]

Further, the sign detection controller 82 includes two systems, that is, a system directly connected to the substrate processing apparatus controller 58 and a system connected to the substrate processing apparatus controller 58 via the DCU 126. Therefore, when the abnormal sign is detected by the sign detection controller 82, a signal can be directly output to the substrate processing apparatus controller 58 without going through the DCU 126 to generate an alarm, and information of the sensor data of the sensor provided at the component in which the abnormal sign is recognized can be displayed on a screen of the display 118 (see FIG. 3).

[0078]

The various sensors 124 are sensors (for example, the pressure sensor 70 and the temperature sensor 106) provided on various components provided in the substrate processing apparatus 10, and are configured to detect parameters of each component such as a flow rate, a concentration, a temperature, a humidity (dew point), a pressure, an electric current, a voltage, a torque, a vibration, a position and a rotation speed.

[0079]

The DCU 126 is configured to collect and accumulate data from the various sensors 124 during executing the process recipe. In addition, the EC 128 is configured to temporarily capture the sensor data as needed depending on a type of the sensor, to apply a processing such as a fast Fourier

transform (hereinafter, abbreviated as “FFT”) to raw data, and then to transmit the raw data on which the processing is applied to the sign detection controller 82.

[0080]

Further, the various sensors 124 are divided into a first sensor system 124A and a second sensor system 124B whose transmission path is different from that of the first sensor system 124A. The first sensor system 124A is a system in which the raw data is captured in real time in units of 0.1 seconds and the raw data is transmitted from the first sensor system 124A to the sign detection controller 82 in real time via the substrate processing apparatus controller 58 and the DCU 126. For example, the first sensor system 124A may include sensors such as a temperature sensor, a pressure sensor and a gas flow rate sensor.

[0081]

On the other hand, the second sensor system 124B is a system in which only a part of the raw data necessary for analysis is captured by applying the processing such as the FFT by the EC 128 and the processed data is transmitted in a processed file format, and the processed data is transmitted from the second sensor system 124B to the sign detection controller 82 via the EC 128. For example, the second sensor system 124B may include a sensor such as a vibration sensor.

[0082]

When the sensor is the vibration sensor, vibration data is accumulated in units of milliseconds, so that an amount of the data becomes enormous. Therefore, when the data is transmitted to the sign detection controller 82 as it is, it leads to a large consumption of a storage capacity of the sign detection controller 82. Since the data of the vibration sensor is finally processed by the processing such as the FFT and used for analysis, by performing the processing in advance with the EC 128, an amount of information can be reduced and information can be transmitted to the sign detection controller 82 in a data format that is easy to analyze.

[0083]

<First Embodiment>

Hereinafter, a first embodiment of a process of detecting the abnormal sign of each component of the substrate processing apparatus 10 using the control system described above will be specifically described.

[0084]

<Calculation of Abnormality Degree>

First, by using values detected by a sensor directly installed on a component subject to an abnormal sign detection and values detected by a sensor of another component whose state directly or indirectly affects a state of the component, an “abnormality degree” is calculated. In the present embodiment, for example, the component subject to the abnormal sign detection is configured such that a value of the abnormality degree thereof generally increases when the component approaches an abnormal state. In addition, the component subject to the abnormal sign detection may be configured such that the value of the abnormality degree thereof generally decreases when the component approaches the abnormal state.

[0085]

<Raw Data Constituting Abnormality Degree>

For example, a sequence of the substrate processing may be constituted by many events with respective purposes such as a loading of the substrate 16 into the process chamber 86, a vacuum-evacuation of the process chamber 86, a temperature elevation, a purge with the inert gas, a wait for the temperature elevation, a processing of the substrate 16 (for example, a film-forming), a replacement of the gas in the process chamber 86, a returning to the atmospheric pressure and an unloading of the substrate 16 after processing the substrate 16. The events described above are examples of the sequence of the substrate processing, and each event may be further subdivided.

[0086]

According to the present embodiment, instead of using the entirety of the sensor data in the

sequence, the value of one or more sensors in one or more specific events among the events described above is used as the raw data to calculate the “abnormality degree” serving as the numerical index in an algorithm. In addition, the value of the abnormality degree for each run is monitored to detect the abnormal sign in each component of the substrate processing apparatus 10. Thereby, it is possible to reduce an accumulation amount of the data by using the data of specific event.

[0087]

For example, the abnormal sign of the vacuum pump 74 may be easily detected at the timing when a large load is applied to the vacuum pump 74. In a step of decreasing the inner pressure of the process chamber 86 from the atmospheric pressure to a predetermined pressure, the large load is applied to the vacuum pump 74 at the timing when the inner pressure of the process chamber 86 is within a pressure band close to the atmospheric pressure at the start of the vacuum-evacuation or several minutes after the start of the vacuum-evacuation.

[0088]

Specifically, the substrate processing apparatus 10 alone may be used to perform a plurality of processes, and different process recipes such as recipes with different film-forming conditions may be mixed with each other and started. Since the source gas flows during the film is formed on the substrate 16, the source gas may react or be thermally decomposed to form a solid substance, which may apply a load on the vacuum pump 74. Therefore, the abnormal sign may be effectively detected by monitoring the film-forming event.

[0089]

On the other hand, the vacuum-evacuation event before the substrate processing tends to remain the same even when the subsequent substrate processing event varies. That is, even when a plurality of recipes with different film-forming conditions are started with the same apparatus, it is possible to predict the temporal change with respect to the same state regardless of the contents of

the substrate processing to thereby make a highly accurate prediction by monitoring the state at the start of the vacuum-evacuation common to each run and acquiring the sensor data.

[0090]

<Examples of Calculating Abnormality Degree>

Hereinafter, an example of calculating the abnormality degree when using the sensor data of the vibration sensor and an example of calculating the abnormality degree when using the sensor data of a sensor other than the vibration sensor (for example, an electric current sensor, a temperature sensor and an exhaust pressure sensor) will be described.

[0091]

First, when determining the presence or absence of the abnormality for each frequency by using the sensor data (vibration data) of the vibration sensor, the procedure is as follows.

[0092]

(1) Among the sensor data in a designated step among those constituting the process recipe, the vibration data (raw data) detected by the vibration sensor is acquired.

(2) The acquired vibration data is converted into a vibration frequency spectrum by the processing such as the FFT, and frequencies in a predetermined range (for example, 10 Hz to 5,000 Hz) of the converted vibration frequency spectrum are extracted at a predetermined frequency interval (for example, every 10 Hz). The numerical value is the amplitude (envelope curve) of the vibration, which is of 500 dimensions in the example.

(3) For each extracted frequency, an average value μ and a standard deviation σ of the amplitude of the vibration frequency spectrum are calculated by using the data of the process recipe executed a predetermined number of times (for example, for 30 runs) under a normal state. Under the assumption that the amplitude under the normal state follows a normal distribution $N(\mu, \sigma)$, the result is used as a normal model.

(4) By using the numerical value of (2) after creating the normal model as an abnormality

degree vector, an amplitude value of the normal model and a predetermined threshold value for each extracted frequency are compared. When the amplitude value of the frequencies deviating from the threshold value is equal to or greater than a predetermined number (for example, m, which is equal to or greater than 1), it is determined that the abnormal sign has occurred (that is, the abnormal sign is present). In addition, the threshold value is calculated, for example, by using the average value μ and the standard deviation σ acquired in (3), wherein the threshold value is within a range (μ ± 3σ) obtained by adding or subtracting the value acquired by multiplying the standard deviation σ by 3 to or from the average value μ.

[0093]

Further, when determining the presence or absence of the abnormality based on a sum of the amplitude of each frequency by using the sensor data (vibration data) of the vibration sensor, the procedure is as follows.

[0094]

(1) Among the sensor data in the designated step among those constituting the process recipe, the vibration data (raw data) detected by the vibration sensor is acquired.

(2) The acquired vibration data is converted into the vibration frequency spectrum by the processing such as the FFT, and the frequencies in the predetermined range (for example, 10 Hz to 5,000 Hz) of the converted vibration frequency spectrum are extracted at the predetermined frequency interval (for example, every 10 Hz). The numerical value is the amplitude (envelope curve) of the vibration, which is of 500 dimensions in the example.

(3) Sums of the extracted amplitudes for each frequency for each run under the normal state are all added (since a sum of the amplitudes is acquired for each run, 30 numbers can be acquired for 30 runs).

(4) Based on a numerical group acquired for each run, an average value μ and a standard deviation σ are acquired. Under the assumption that the sum acquired for each run follows the

normal distribution N (μ, σ), the result is used as a normal model.

(5) By using the numerical value of (3) after creating the normal model as the abnormality degree, the amplitude value of the normal model and a predetermined threshold value are compared. When the amplitude value of the normal model deviates from the predetermined threshold value, it is determined that the abnormal sign has occurred (that is, the abnormal sign is present). In addition, the threshold value is calculated, for example, by using the average value μ and the standard deviation σ acquired in (3), wherein the threshold value is within the range (μ ± 3σ) obtained by adding or subtracting the value acquired by multiplying the standard deviation σ by 3 to or from the average value μ.

[0095]

Further, when determining the presence or absence of the abnormality based on each basic statistic by using the sensor data other than the vibration data, the procedure is as follows.

[0096]

(1) One or more data under the normal state are selected from the basic statistics of an average value, a standard deviation, an N quantile, a maximum value and minimum value of the sensor data of a target event.

(2) For each selected basic statistic of the normal state, an average value μ thereof and a standard deviation σ thereof are acquired. Under the assumption that each selected basic statistic follows the normal distribution N (μ, σ), the result is used as a normal model for each basic statistic of the sensor data.

(3) By using the value of (1) after creating the normal model as the abnormality degree, the value and a predetermined threshold value are compared for each basic statistic of the sensor data. When the value deviates from the predetermined threshold value, it is determined that the abnormal sign has occurred (that is, the abnormal sign is present). In addition, the threshold value is calculated, for example, by using the average value μ and the standard deviation σ acquired in (2), wherein the

threshold value is within the range ($\mu \pm 3\sigma$) obtained by adding or subtracting the value acquired by multiplying the standard deviation σ by 3 to or from the average value μ.

[0097]

Further, as shown in FIG. 6, when determining the presence or absence of the abnormality based on a singular spectrum transformation by using the sensor data other than the vibration data, the procedure is as follows. In addition, in the following procedure, two data matrices X and Z are created for the past and the present by using a partial time series of a window width n around a run p. The following procedure is a general method of the singular spectrum transformation.

[0098]

(1) Regarding each as an M-dimensional vertical vector, an Mn-dimensional vertical vector is prepared by connecting n number of the M-dimensional vertical vectors vertically from the top S (p - n + 1, 1) to the bottom S (p, M).

Sensor data at time 1, 2, ..., M of the target event of a run (p - n + 1)

{S (p - n + 1, 1), S (p - n + 1, 2), ... , S (p - n + 1, M)}

...

Sensor data at time 1, 2, ..., M of the target event of a run (p - 1)

{S (p - 1, 1), S (p - 1, 2), ..., S (p - 1, M)}

Sensor data at time 1, 2, ..., M of the target event of the run p

{S (p, 1), S (p, 2), ..., S (p, M)}

(2) Regarding each as an M-dimensional vertical vector, an Mn-dimensional vertical vector is prepared by connecting n number of the M-dimensional vertical vectors, which are of one-time earlier run than those of (1), vertically from the top S (p - n + 1, 1) to the bottom S (p, M).

Sensor data at time 1, 2, ..., M of the target event of a run (p - n)

{S (p - n, 1), S (p - n, 2), ..., S (p - n, M)}

...

Sensor data at time 1, 2, ..., M of the target event of a run (p - 2)

{S (p - 2, 1), S (p - 2, 2), ..., S (p - 2, M)}

Sensor data at time 1, 2, ..., M of the target event of the run (p - 1)

{S (p - 1, 1), S (p - 1, 2), ..., S (p - 1, M)}

(3) Similar to the above (1) and (2), K vertical vectors arranged in order are prepared, and a Mn × K-dimensional matrix X (p) is created by arranging the vertical vectors from left to right and from the oldest to the newest. Thereby, a history matrix for performing the singular spectrum transformation is created.

(4) Regarding each as an M-dimensional vertical vector, an Mn-dimensional vertical vector is prepared by connecting n number of the M-dimensional vertical vectors vertically from the top S (p + L, 1) to the bottom S (p + L - n + 1, M). Herein, L is set to be a positive integer.

Sensor data at time 1, 2, ..., M of the target event of a run (p + L)

{S (p + L, 1), S (p + L, 2), ..., S (p + L, M)}

...

Sensor data at time 1, 2, ..., M of the target event of a run (p + L - n + 2)

{S (p + L - n + 2, 1), S (p + L - n + 2, 2), ..., S (p + L - n + 2, M)}

Sensor data at time 1, 2, ..., M of the target event of a run (p + L - n + 1)

{S (p + L - n + 1, 1), S (p + L - n + 1, 2), ..., S (p + L - n + 1, M)}

(5) Regarding each as an M-dimensional vertical vector, an Mn-dimensional vertical vector is prepared by connecting n number of the M-dimensional vertical vectors, which are of one-time earlier run than those of (1), vertically from the top S (p + L - 1, 1) to the bottom S (p + L - n, M) .

Sensor data at time 1, 2, ..., M of the target event of a run (p + L - 1)

{S (p + L - 1, 1), S (p + L-1, 2), ..., S (p + L-1, M)}

...

Sensor data at time 1, 2, ..., M of the target event of a run (p + L - n + 1)

{S (p + L - n + 1, 1), S (p + L - n + 1, 2), ..., S (p + L - n + 1, M)}

Sensor data at time 1, 2, ..., M of the target event of a run (p + L - n)

{S (p + L - n, 1), S (p + L - n, 2), ..., S (p + L - n, M)}

(6) Similar to the above (4) and (5), R vertical vectors arranged in order are prepared, and a Mn × R-dimensional matrix Z (p) is created by arranging the vertical vectors from left to right and from the oldest to the newest. Thereby, a test matrix for the singular spectrum transformation is created.

(7) Singular value decomposition is performed on the matrix X (p) and matrix Z (p) described above, and the singular spectrum transformation is performed.

(8) A matrix U (r) and a matrix Q (m) are created by selecting r number of left singular vectors acquired by the singular value decomposition in X (p) and m number of left singular vectors acquired by the singular value decomposition in Z (p), respectively. Then, a maximum singular value is obtained by calculating the product $U(r)^T Q(m)$. Denoting the maximum singular value as λ (λ is equal to or greater than 0 and equal to or less than 1), let 1-λ be the abnormality degree (degree of change). When the abnormality degree deviates from a predetermined threshold value, it is determined that the abnormal sign is present.

[0099]

<Determination of Abnormal Sign Using Abnormality Degree>

Further, as a method of determining the presence or absence of the abnormal sign by using the abnormality degree, for example, the following methods may be considered. When it is determined that the abnormal sign is present, the substrate processing apparatus controller 58 is notified of such information.

[0100]

(1) A method of determining that the abnormal sign is present when the abnormality degree of at least one sensor data deviates from the threshold value.

(2) A method of determining that the abnormal sign is present when the abnormality degree of two or more sensor data deviates from the threshold value.

(3) A method of determining that the abnormal sign is present when the abnormality degree of one or more sensor data deviates from the threshold value a predetermined number of times (for example, three times).

(4) A method of determining that the abnormal sign is present when the abnormality degree of the sensor data other than the vibration data consecutively deviates from the threshold value for a predetermined number of times (for example, three times).

(5) A method of determining that the abnormal sign is not present when the abnormality degree of the vibration data does not deviate from the threshold value even when the abnormality degree of the sensor data other than the vibration data deviates from the threshold value.

(6) A method of determining that the abnormal sign is present when both the abnormality degree of the vibration data and the abnormality degree of the sensor data other than the vibration data deviate from the threshold value.

[0101]

For example, in the methods (2), (5) and (6) described above, since the abnormal sign is determined by using a plurality of sensor data, it is possible to reduce a false detection of the sensor. Further, since a temporal behavior of the abnormality degree is not always monotonous, the methods (3) and (4) described above can reduce an erroneous determination when the value of the abnormality degree fluctuates around the threshold value. Further, the calculation formula, the threshold value and the program of the abnormality degree may be different for each component and each apparatus, and may be incorporated in the sign detection controller 82 in advance.

[0102]

<Display of Analysis Screen for Abnormal Sign Detection>

An analysis screen configured to detect the abnormal sign may be displayed on the display

118 (see FIG. 3) of the substrate processing apparatus controller 58. Therefore, data such as a transition of the abnormality degree, the threshold value and the number of times the value exceeds threshold value can be visually observed, and the state of the component can be confirmed by the abnormality degree.

[0103]

<Case Involving EC>

Here, a case of the second sensor system 124B shown in FIG. 5, that is, the case where the EC 128 is interposed between the sensor and the sign detection controller 82 will be described.

[0104]

<Time Synchronization>

Since the vibration sensor data is converted by the EC 128, when it is transmitted to the sign detection controller 82, the time of the vibration sensor data is synchronized with the EC 128. In order to perform analysis by simultaneously using the data of the vibration sensor and the data of other sensors whose time is synchronized with the DCU 126 or the substrate processing apparatus controller 58, the time of the former should be synchronized with the time of the latter. Therefore, the EC 128, the DCU 126 and the sign detection controller 82 periodically capture the time, which are synchronized with the time of the substrate processing apparatus controller 58 as a reference time. As a result, the time of entire components can be synchronized, and an accurate analysis can be possible.

[0105]

In the present embodiment, the method of detecting the abnormal sign of the component of the substrate processing apparatus 10 will be specifically described by way of an example in which the vacuum pump 74 (see FIG. 2) is used as the component.

[0106]

Reaction by-products of the process gas may be deposited in the process chamber 86 of the

substrate processing apparatus 10, and when an amount or height of the reaction by-products reaches a certain level, the rotation of the vacuum pump 74 suddenly stops.

[0107]

In the present embodiment, by continuously monitoring at least one sensor data among the electric current data, temperature data, exhaust pressure data and the vibration data of the vacuum pump 74, and by analyzing the change in the behavior of the sensor data by the sign detection program in the sign detection controller 82, it is possible to detect the abnormal sign of the vacuum pump 74. When the abnormal sign is detected, the information is transmitted to the substrate processing apparatus controller 58, and an operating person is notified of it to replace or maintain the vacuum pump 74.

[0108]

<Second Embodiment>

Hereinafter, a second embodiment of the process of detecting the abnormal sign of each component of the substrate processing apparatus 10 by using the control system described above will be specifically described. In the second embodiment, the configuration of components such as the sign detection controller 82 and the abnormal sign determination using the abnormality degree are the same as those in the first embodiment.

[0109]

<Calculation of Abnormality Degree>

According to the second embodiment, by using values of the sensor installed on the component subject to the abnormal sign detection and values of the sensor of another component whose state directly or indirectly affects the state of the component, the sensor data under the normal state is learned, and the “abnormality degree” is calculated by using the learned data and the data in operation.

[0110]

In the present embodiment, for example, the component subject to the abnormal sign detection is configured such that the value of the abnormality degree thereof generally increases when the component approaches the abnormal state. In addition, the component subject to the abnormal sign detection may be configured such that the value of the abnormality degree thereof generally decreases when the component approaches the abnormal state.

[0111]

In the present embodiment, the method of detecting the abnormal sign of the component of the substrate processing apparatus 10 will be specifically described by way of an example in which the vacuum pump 74 (see FIG. 2) is used as the component.

[0112]

In general, when the process chamber 86 is vacuum-evacuated by the vacuum pump 74, the inert gas or a film-forming gas flows through the vacuum pump 74, and the vacuum pump 74 is in a state subject to a high load. Therefore, it becomes easy to detect the abnormal sign. On the other hand, when the process chamber 86 is not vacuum-evacuated by the vacuum pump 74, and the vacuum pump 74 is in a state subject to a low load. Therefore, it becomes difficult to detect the abnormal sign or it becomes unlikely for the abnormality to occur. Therefore, conventionally, the vacuum pump 74 has been monitored while the process chamber 86 is being vacuum-evacuated.

[0113]

On the other hand, according to the present embodiment, in an event in which the process chamber 86 is not vacuum-evacuated by the vacuum pump 74 and the substrate 16 is not in the process chamber 86, a large amount of the gas is intentionally provided to the vacuum pump 74 to increase the load on the vacuum pump 74. Then, under such a state, by monitoring data of the vacuum pump 74 such as the electric current data, the vibration data, the temperature data and a back pressure data, it becomes easy to detect the abnormal sign.

[0114]

In this way, by applying the load to the vacuum pump 74 in the state where the process chamber 86 is not vacuum-evacuated, it is possible to prevent a loss from occurring in the substrate 16 even when the vacuum pump 74 is stopped by the applied load. Further, when the vacuum pump 74 is stopped by applying the load while the process chamber 86 is not vacuum-evacuated, it is considered that the vacuum pump 74 is in a state immediately before the failure. Therefore, as a result, it is possible to avoid a situation in which the vacuum pump 74 is stopped while the process chamber 86 is being vacuum-evacuated, that is, while the substrate processing is being performed.

[0115]

<Third Embodiment>

Hereinafter, a third embodiment of the process of detecting the abnormal sign of each component of the substrate processing apparatus 10 by using the control system described above will be specifically described. In the third embodiment, the configuration of components such as the sign detection controller 82 and the abnormal sign determination using the abnormality degree are the same as those in the first embodiment and the second embodiment.

[0116]

In the present embodiment, when the component subject to the abnormal sign detection is replaced or maintained, a normal model after the replacement or the maintenance is created, the substrate processing apparatus 10 is monitored based on the normal model to monitor the abnormal sign, and the abnormal sign determination is performed.

[0117]

According to the present embodiment, the replacement or the maintenance of the component subject to the abnormal sign detection is automatically or semi-automatically detected. For example, when accumulated operation time information is provided for the component subject to the abnormal sign detection, the replacement of the component can be detected by using the accumulated operation time information. Since the accumulated operation time of the component subject to the abnormal

sign detection is usually stored in a non-volatile memory medium, an operation time is accumulated until the component is replaced, and the operation time is reset by the replacement. Therefore, by monitoring an accumulated operation time of the component subject to the abnormal sign detection, it is possible to detect that the component has been replaced when the accumulated operation time is reduced.

[0118]

Specifically, the substrate processing apparatus controller 58 transmits the accumulated operation time of the component subject to the abnormal sign detection to the sign detection controller 82 at predetermined time intervals, and the sign detection controller 58 determines whether the newly transmitted accumulated operation time is shorter than the accumulated operation time stored before. When the determination result is affirmative, it is possible to determine that the component has been replaced.

[0119]

Alternatively, even when the accumulated operation time is not provided for the component subject to the abnormal sign detection, the replacement of the component can be detected by, instead of the accumulated operation time, performing an operation of disconnecting a signal connector at the time of the replacement of the component. In the operation of disconnecting the signal connector when replacing the component, a signal line of the component is opened (disconnected). Then, the operating person is urged to input a confirmation whether or not the signal line has been replaced or maintained when the signal line is turned on next time. For example, other operation cannot be started without the confirmation input on the operation screen. As a result, it is possible to determine that the component has been replaced semi-automatically.

[0120]

When it is determined that the component subject to the abnormal sign detection has been replaced or maintained, as a part of a sign detection process, the sign detection controller 82 newly

acquires the sensor data for the component subject to the abnormal sign detection and updates the normal model. Then, the abnormality degree is calculated based on the updated normal model. The calculation of the abnormality degree and the detection of the sign by monitoring the value of the abnormality degree may be performed in the same manner as in the first embodiment and the second embodiment.

[0121]

In the present embodiment, the method of detecting the abnormal sign of the substrate processing apparatus 10 will be specifically described by way of an example in which the vacuum pump 74 (see FIG. 2) is replaced.

[0122]

The substrate processing apparatus controller 58 is configured to acquire the operation time as the sensor data of the vacuum pump 74 and to accumulate the acquired operation time of the vacuum pump 74 until the vacuum pump 74 is replaced, and to reset the operation time (accumulated operation time) when the vacuum pump 74 is replaced. Further, as shown in FIG. 5, the substrate processing apparatus controller 58 is connected to the sign detection controller 82, and transmits the accumulated operation time to the sign detection controller 82 at the predetermined time intervals. In addition, the time (accumulated operation time) acquired by accumulating the operation time of the vacuum pump 74 may also be managed by the sign detection controller 82 by directly acquiring the operation time from the vacuum pump 74.

[0123]

As shown in FIG. 7, as a part of the sign detection process, the sign detection controller 82 acquires the accumulated operation time transmitted from the substrate processing apparatus controller 58 (S10), and determines whether or not it is shorter than the accumulated operation time stored before (S12). When the determination result is affirmative, the sign detection controller 82 determines that the vacuum pump 74 has been replaced, and acquires the sensor data for creating the

normal model after the replacement (S14). For example, the sign detection controller 82 acquires the sensor data of the process recipe executed a predetermined number of times (for example, for 30 runs). Then, the sign detection controller 82 creates the normal model based on the acquired sensor data (S15). For example, the average value μ and the standard deviation σ are acquired by using the sensor data of the process recipe executed the predetermined number of times. Under the assumption that each sensor data under the normal state follows the normal distribution N (μ, σ), the result is used as the normal model. Based on the acquired normal model, the abnormality degree is calculated (S16), and the previously stored data of the abnormality degree is rewritten by the calculated abnormality degree (S17). Then, the substrate processing apparatus 10 is monitored (S18), and the abnormal sign determination is performed. The calculation of the abnormality degree and the monitoring of the value of the abnormality degree may be performed in the same manner as in the first embodiment and the second embodiment.

[0124]

According to the present embodiment, the normal model is newly created after the component subject to the abnormal sign detection is replaced or maintained, so that the appropriate abnormal sign detection can be performed (that is, it is possible to detect that the abnormal sign is being generated). Further, since the replacement or the maintenance of the component subject to the abnormal sign detection is automatically or semi-automatically detected, it is possible to appropriately change the value of the abnormality of the component to be monitored.

[0125]

<Fourth Embodiment>

Hereinafter, a fourth embodiment of the process of detecting the abnormal sign of each component of the substrate processing apparatus 10 by using the control system described above will be specifically described. In the fourth embodiment, the configuration of components such as the sign detection controller 82 and the abnormal sign determination using the abnormality degree are

the same as those in the first embodiment through the third embodiment.

[0126]

In the present embodiment, when the component subject to the abnormal sign detection is replaced or maintained, before the normal model after the replacement or the maintenance is newly created, it is determined whether to create the new normal model or continue to use the normal model before the replacement or the maintenance. The replacement or the maintenance of the component subject to the abnormal sign detection is automatically or semi-automatically detected in the same manner as that in the third embodiment.

[0127]

Specifically, when it is determined that the component subject to the abnormal sign detection has been replaced or maintained, the sign detection controller 82 acquires the sensor data whose amount is smaller than that of the sensor data required to create the normal model. Then, based on the acquired sensor data, it is determined whether or not the normal model before the replacement or the maintenance can be continuously used.

[0128]

When it is determined that the use of the normal model before the replacement or the maintenance can be continued, the normal model before the replacement or the maintenance is used without acquiring the sensor data required to create the normal model. Therefore, the calculation of the abnormality degree may not be performed, and the value of the abnormality degree before the replacement or the maintenance is monitored as before to perform the sign detection.

[0129]

When it is determined that the normal model before the replacement or the maintenance cannot be used anymore, the acquisition of the sensor data is further performed until the sensor data required to create the normal model is acquired, and thereafter the normal model is newly created. Then, the abnormality degree is calculated based on the newly created normal model, and the newly

created value of the abnormality degree is monitored to perform the sign detection.

[0130]

In the present embodiment, the method of detecting the abnormal sign of the substrate processing apparatus 10 will be specifically described by way of an example in which the vacuum pump 74 (see FIG. 2) is replaced.

[0131]

<Specific Example>

As shown in FIG. 8, the sign detection controller 82 acquires the accumulated operation time transmitted from the substrate processing apparatus controller 58 (S30), and determines whether or not it is shorter than the accumulated operation time stored before (S32). When the determination result is affirmative, the sign detection controller 82 determines that the vacuum pump 74 has been replaced, and acquires the sensor data (the sensor data for determination) required to determine whether or not the normal model before the replacement can be used (S33). A data amount of the sensor data required for the determination is a smaller amount (e.g.,, for 10 runs) than the data amount of the sensor data of the process recipe for creating the a normal model executed a predetermined number of times (e.g., for 30 runs). Then, it is statistically determined whether or not a distribution of the acquired sensor data for the determination is equal to a data distribution of the normal model before the replacement, and it is determined whether or not the normal model before the replacement can be used (S34).

[0132]

For example, the statistical determination may be performed as follows.

(1) For each of a data group before the replacement and a data group after the replacement, a normality is determined by the Shapiro-Wilk test.

(2) By using the F-test, it is determined whether or not variances of the data group before the replacement and the data group after the replacement are equal to each other.

(3) Based on results of the above (1) and (2), a difference in the average values (representative values) is tested by one of Student's t-test, Welch's t-test and Mann-Whitney's U-test.

[0133]

When the distribution of the acquired sensor data is equal to the data distribution of the normal model before the replacement, it is determined that the normal model before the replacement can be used (“Y”), and the sign detection is performed by monitoring the value of the abnormality degree by using the normal model before the replacement (S39) without acquiring the sensor data for creating the normal model.

[0134]

When the distribution of the acquired sensor data is not equal to the data distribution of the normal model before the replacement, it is determined that the normal model before the replacement cannot be used (“N”), and the acquisition of the sensor data is further performed (S35). After the sensor data for creating the normal model is obtained, the normal model is newly created (S36). Then, based on the obtained normal model, the abnormality degree is calculated (S37), and the previously stored data of the abnormality degree is rewritten by the calculated abnormality degree (S38). Then, the substrate processing apparatus 10 is monitored (S39), and the abnormal sign determination is performed. The calculation of the abnormality degree and the monitoring of the value of the abnormality degree may be performed in the same manner as in the first embodiment and the second embodiment.

[0135]

According to the present embodiment, by acquiring a smaller amount of the sensor data than that of the sensor data required to create the normal model for the component subject to the abnormal sign detection, it is determined whether or not the normal model before the replacement or the maintenance of the component can be used. Therefore, it is possible to shorten a time during which the monitoring for detecting the abnormal sign is stopped by creating the normal model.

[0136]

<Application and Effect>

According to the above embodiment, since the substrate processing apparatus 10 includes the control system configured to detect the abnormal sign of the component, the component can be replaced or maintained when the abnormal sign of the component is detected by the control system. In particular, regarding the detection of the failure sign of the vacuum pump 74, an accuracy of the abnormal sign can be improved by continuously monitoring the sensor data such as the electric current data, the temperature data, the exhaust pressure data and the vibration data of the vacuum pump 74.

[0137]

As a result, it is possible to take measures such as the replacement before the component fails, and it is possible to reduce the replacement frequency by using the component until immediately before the failure of the component. Further, by preventing the failure of the component during the substrate processing, it is possible to improve an apparatus operation rate, to prevent a decrease in the yield of the product (that is, the substrate 16) and to reduce the unnecessary maintenance time.

[0138]

Further, according to the above embodiment, the sign detection controller 82 configured to detect the abnormal sign is connected to the substrate processing apparatus controller 58. Therefore, it is possible to acquire and analyze the data by limiting to a specific substrate processing sequence during which the abnormal sign can be easily detected.

[0139]

Further, even after the replacement or the maintenance of the component subject to the abnormal sign detection, it is possible to detect the abnormal sign of the component subject to the abnormal sign detection by using an appropriate normal model.

[0140]

<Other Embodiments>

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

[0141]

For example, while the above-described embodiments are described by way of an example in which the film is formed on the substrate 16, the present disclosure is not limited thereto. For example, the present disclosure may be preferably applied to processes such as an oxidation process, a diffusion process, an annealing process and an etching process of the film formed on the substrate 16.

[0142]

In addition, while the above-described embodiments are described by way of an example in which the substrate processing apparatus 10 provided with the hot wall type process furnace 44 is used to form the film, the present disclosure is not limited thereto. For example, the present disclosure may be preferably applied to form the film using a substrate processing apparatus provided with a cold wall type process furnace. In addition, while the above-described embodiments are described by way of an example in which the batch type substrate processing apparatus 10 configured to simultaneously process the plurality of substrates 16 is used to form the film, the present disclosure is not limited thereto.

[0143]

In addition, the present disclosure is not limited to the semiconductor manufacturing apparatus such as the substrate processing apparatus 10 according to the above-described embodiments. The present disclosure may also be applied to an apparatus such as an LCD (Liquid Crystal Display) manufacturing apparatus configured to process a glass substrate.

[Description of Reference Numerals]

[0144]

10	substrate processing apparatus
16	substrate
58	substrate processing apparatus controller (an example of a main controller)
74	vacuum pump
82	sign detection controller (an example of a sign detector)
86	process chamber
μ	average value
σ	standard deviation

[CLAIMS]

[Claim 1]

A substrate processing apparatus configured to acquire sensor data related to a component subject to an abnormal sign detection, to create a normal model, and to monitor an apparatus state based on the normal model, comprising

a sign detector configured to: acquire the sensor data after a replacement or a maintenance of the component subject to the abnormal sign detection; re-create the normal model from the sensor data; and detect an abnormal sign before an abnormal apparatus stop occurs by monitoring the apparatus state based on the normal model.

[Claim 2]

The substrate processing apparatus of claim 1, wherein the sign detector is further configured to determine, based on the sensor data whose data amount is smaller than an amount of data required to create the normal model, whether or not the normal model before the replacement or the maintenance is appropriate to be used as the normal model after the replacement or the maintenance.

[Claim 3]

The substrate processing apparatus of claim 2, wherein the sign detector is configured to:

use the normal model before the replacement or the maintenance as the normal model after the replacement or the maintenance when it is determined that the normal model before the replacement or the maintenance is appropriate to be used as the normal model after the replacement or the maintenance; and

acquire the sensor data and create the normal model after the replacement or the maintenance based on the sensor data when it is determined that the normal model before the replacement or the maintenance is not appropriate to be used as the normal model after the replacement or the maintenance.

[Claim 4]

The substrate processing apparatus of claim 1, further comprising

a main controller configured to control a predetermined process on a substrate by executing a process recipe constituted by a plurality of steps,

wherein the sign detector is configured to:

collect the sensor date while performing the process recipe;

acquire vibration data detected by a vibration sensor among the sensor data in a designated step of the plurality of steps constituting the process recipe;

convert the acquired vibration data into a vibration frequency spectrum;

extract the converted vibration frequency spectrum at predetermined frequency intervals;

calculate an average value and a standard deviation of an amplitude of the vibration frequency spectrum for each extracted frequency by using data of the process recipe executed a predetermined number of times under a normal state;

re-create the normal model by using the acquired average value and the acquired standard deviation of the amplitude of the vibration frequency spectrum.

[Claim 5]

The substrate processing apparatus of claim 4, wherein the designated step comprises decreasing an inner pressure of a process chamber in which the substrate is processed from an atmospheric pressure to a predetermined pressure.

[Claim 6]

The substrate processing apparatus of claim 4, wherein the sign detector is configured to:

create the normal model by using the average value and the standard deviation of the amplitude of the vibration frequency spectrum; compare an amplitude value of the normal model with a predetermined threshold value for the extracted frequency; and determine that the abnormal sign is present when the number of amplitude values of frequencies deviating from the threshold

value is equal to or greater than a predetermined number.

[Claim 7]

The substrate processing apparatus of claim 6, wherein the predetermined threshold value is calculated, by using the average value and the standard deviation, to fall within a range from a value obtained by subtracting three times of the standard deviation from the average value to a value obtained by adding three times of the standard deviation to the average value.

[Claim 8]

The substrate processing apparatus of claim 6, wherein the sign detector is further configured to: generate an alarm when it is determined that the abnormal sign is present, and display, on a screen, the sensor data of the component in which the abnormality sign is recognized.

[Claim 9]

The substrate processing apparatus of claim 4, wherein the component subject to the abnormal sign detection comprises an exhauster configured to exhaust an inner atmosphere of a process chamber in which the substrate is processed, and

the sign detector is further configured to create the normal model by acquiring at least one sensor data selected from the group consisting of the vibration data detected by the vibration sensor, electric current data of the exhauster, temperature data of the exhauster and exhaust pressure data of the exhauster.

[Claim 10]

A method of manufacturing a semiconductor device, comprising

a substrate processing of performing a predetermined process on a substrate by executing a process recipe constituted by a plurality of steps,

wherein the substrate processing further comprises:

a step of re-creating a normal model by acquiring sensor data subject to an abnormal sign detection after a replacement or a maintenance of a component; and

a step of detecting an abnormal sign before an abnormal apparatus stop occurs by monitoring an apparatus state based on the normal model.

[Claim 11]

A sign detection program executed by a substrate processing apparatus configured to acquire sensor data related to a component subject to an abnormal sign detection, to create a normal model and to monitor an apparatus state based on the normal model, wherein the sign detection program causes, by a computer, the substrate processing apparatus to perform:

a sequence of re-creating a normal model by acquiring sensor data subject to an abnormal sign detection after a replacement or a maintenance of a component; and

a sequence of detecting an abnormal sign before an abnormal apparatus stop occurs by monitoring an apparatus state based on the normal model.