HEAT TREATMENT APPARATUS AND HEAT TREATMENT METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a heat treatment apparatus for subjecting substrates such as semiconductor wafers to a heat treatment process, and a heat treatment method therefor.

Background Art

In a manufacturing process of a semiconductor device, a vertical heat treatment apparatus is used, in which a plurality of semiconductor wafers are subjected to a heat treatment process such as a film-forming process by a CVD (chemical vapor deposition) method, an oxidation, and a diffusion. For example, a holder referred to as a wafer boat, which holds thereon a plurality of wafers in a tier-like manner, is loaded from below into a vertical heat treatment oven of the heat treatment apparatus. Then, a process atmosphere therein is heated to a predetermined temperature, so as to subject the wafers to a heat treatment process. Generally, the heat treatment oven includes a plurality of vertically divided zones to be heated. In order that the temperatures in the respective zones can be separately controlled, the heat treatment apparatus also includes a plurality of heating means, and a plurality of temperature control means corresponding thereto.

The inventors of the present invention have studied a vertical heat treatment apparatus shown in Fig. 8, in which a carbon wire heater is used as heating means. In Fig. 8, the reference number 101 represents a reaction vessel having a lower opening 102. A heating mechanism 200, which is divided into, e.g., three heaters, is disposed around the reaction vessel 101. The heating mechanism 200 includes a main heater 202 for heating a larger part of a heat treatment area, a sub-heater 201 provided above the main heater 202, and a sub-heater 203 provided below the main heater 202. When a wafer boat 103

holding thereon a plurality of wafers W in a tier-like manner is loaded into the reaction vessel 101 through the opening 102, the opening 102 is closed by a cover 104 disposed on a lower end of the wafer boat 103. Then, the inside of the reaction vessel 101 is heated to a predetermined temperature, so that the wafers W are subjected to a predetermined heat treatment.

In order to detect a temperature in a heat treatment atmosphere heated by the heaters 201 to 203 of the heating mechanism 200, inner thermocouples 301 to 303 of an inner temperature detecting part 300 are disposed inside the reaction vessel 101, and outer thermocouples 401 to 403 of an outer temperature detecting part 400 are disposed near the heaters 201 to 203 of the heating mechanism 200. Controlling parts 501 to 503 of a controlling mechanism 500 are disposed corresponding to the heaters 201 to 203 of the heating mechanism 200. Detected temperature values detected by the inner thermocouples 301 to 303 and the outer thermocouples 401 to 403 are sent to the controlling parts 501 to 503. The controlling parts 501 to 503 can independently control heat generation amounts of the heaters 201 to 203, based on the detected temperature values and target temperature values set for the respective zones.

When loading the wafer boat 103 into the reaction vessel 101, the temperature near the lowermost sub-heater 203 is lower than the temperature near the main heater 202. This is because the temperature near the lowermost sub-heater 203 is affected by an outside atmosphere flowing into the reaction vessel 101 through the opening 102. In this state, the cooled wafers W and the wafer boat 103 (of a lower temperature than that in the reaction vessel 101) are loaded into the reaction vessel 101 through the opening 102, and then the temperature near the sub-heater 203 is further lowered. Thereafter, as the wafer boat 102 is elevated, the temperatures near the main heater 202 and the uppermost sub-heater 201 are lowered.

That is, in the reaction vessel 101, the temperature near the uppermost sub-heater 201 is the highest, while the

temperature near the lowermost heater 203 is the lowest. As the wafer boat 103 is elevated, the temperatures of the wafers W and the wafer boat 103 are gradually raised by the heat from the heating mechanism 200. Therefore, a temperature distribution near the heating mechanism 200 in the vertical direction rapidly changes in accordance with a position of the wafer boat 103. Upon the loading of the wafer boat 103 into the reaction vessel 101, the temperature near the lowermost sub-heater 203 is abruptly lowered. Thus, the controlling part 503 controls the sub-heater 203 such that a larger power is supplied thereto. Because of the loading of the wafer boat 103, the temperature near the main heater 202 is also lowered, but the temperature near the main heater 202 is higher than that near the lowermost sub-heater 203. Thus, a power to be supplied to the main heater 202 by the controlling part 502 is smaller than the power to be supplied to the sub-heater 203. Namely, the temperature control of the main heater 202 and the temperature control of the sub-heater 203 are separately carried out, and thus are different from each other. In addition, when a temperature distribution near the heating mechanism 200 in the vertical direction changes, the temperature control of each of the heaters 202 and 203 also changes. Further, temperature changes near the heaters 202 and 203 influence to each other.

The temperature control of the uppermost sub-heater 201 and the temperature control of the main heater 202 are also separate and different from each other. Therefore, there arises a problem in that it takes a long time for the temperature near the heater 200 to become stable, after the wafer boat 103 is completely loaded into the reaction vessel 101. After the wafer boat 103 is completely loaded into the reaction vessel 101, the inside of the reaction vessel 101 is generally heated to a predetermined process temperature. At this time, unless the temperature in the reaction vessel 101 has been stabilized before the reaction vessel 101 is heated, it takes a long time to obtain a stabilized process temperature, which results in a poor

throughput.

SUMMARY OF THE INVENTION

The present invention is made in view of the above problems. An object thereof is to provide an art, when substrates are treated in a heat treatment atmosphere which is divided into a plurality of zones, to promptly stabilize the temperatures in the respective zones so that an improved throughput can be provided.

The present invention is a heat treatment apparatus comprising: a reaction vessel divided into a plurality of zones; a substrate holder to be loaded into the reaction vessel, for holding thereon a plurality of substrates; heating means provided at the respective zones; temperature detecting parts provided at the respective zones; and controlling parts provided at the respective zones, for independently controlling the respective heating means; wherein the controlling part corresponding to a certain zone includes a first calculation part for calculating a control signal, when the substrates are loaded into the reaction vessel, based on a detected temperature value detected by the temperature detecting part corresponding to the certain zone, by using as a target temperature value, a detected temperature value detected by the temperature detecting part corresponding to another zone, and outputting the control signal for controlling the corresponding heating means.

In the heat treatment apparatus, each of the temperature detecting part may include a first temperature detector for detecting a temperature near the corresponding heating means, and the detected temperature value detected by the temperature detecting part corresponding to another zone may be a detected temperature value detected by the first temperature detector.

In the heat treatment apparatus, each of the temperature detecting part may include a second temperature detector for detecting a temperature in the corresponding zone of the

reaction vessel, and the detected temperature value detected by the temperature detecting part corresponding to another zone may be a detected temperature value detected by the second temperature detector.

In the heat treatment apparatus, the controlling part corresponding to the certain zone may further include a second calculation part for calculating a control signal, when the substrates are subjected to a heat treatment process process, based on the target temperature value set for the certain zone and the detected temperature value detected by the temperature detecting part corresponding to the certain zone, and outputting the control signal for controlling the corresponding heating means.

In the heat treatment apparatus, each of the temperature detecting part may include the first temperature detector for detecting a temperature near the corresponding heating means, and the second temperature detector for detecting a temperature in the corresponding zone of the reaction vessel, the first calculation part of the controlling part corresponding to the certain zone may calculate a control signal, when the substrates are loaded into the reaction vessel, by using as a target temperature value, the detected temperature value detected by the first temperature detector or the second temperature detector corresponding to another zone, and output the control signal for controlling the corresponding heating means, and the controlling part corresponding to the certain zone may further include the second calculation part for calculating a control signal, when the substrates are subjected to a heat treatment process process, based on the target temperature values set for the certain zone and the respective detected temperature values detected by the first temperature detector and the second temperature detector corresponding to the certain zone, and outputting the control signal for controlling the corresponding heating means.

In the heat treatment apparatus, the first calculation part of the controlling part corresponding to the certain zone may

calculate the control signal based on a deviation between a value obtained by adding a correction value to the detected temperature value detected by the temperature detecting part corresponding to another zone and the detected temperature value detected by the temperature detecting part corresponding to the certain zone, and output the control signal for controlling the corresponding heating means.

In the heat treatment apparatus, when the substrates are subjected to a heat treatment process process, the first calculation part of the controlling part corresponding to the certain zone may use as the correction value, a difference between the target temperature value set for the certain zone and the target temperature value corresponding to another zone.

In the heat treatment apparatus, the first calculation part of the controlling part corresponding to the certain zone may calculate the control signal, based on a value obtained by multiplying the deviation between a value obtained by adding the correction value to the detected temperature value detected by the temperature detecting part corresponding to another zone and the detected temperature value detected by the temperature detecting part corresponding to the certain zone, by a predetermined ratio.

In the heat treatment apparatus, the reaction vessel may be of a vertical type and the substrate holder is loaded into the reaction vessel from a lower part thereof, the reaction vessel may be vertically divided into at least three zones in which the certain zone is a lowermost zone and another zone is a zone other than an uppermost one.

The present invention is a heat treatment method for subjecting substrates to a heat treatment, by loading a substrate holder holding thereon a plurality of substrates into a reaction vessel divided into a plurality of zones, and heating the plurality of zones by heating means respectively corresponding thereto, comprising the steps of: detecting a temperature value corresponding to each of the zones; and controlling each of the

heating means based on a target temperature value and the detected temperature value of the corresponding zone; wherein when the substrate holder is loaded into the reaction vessel, the heating means corresponding to a certain zone is controlled by using, as the target temperature value for the certain zone, a detected temperature value corresponding to another zone.

In the heat treatment method, when the substrate holder is loaded into the reaction vessel, the heating means corresponding to the certain zone may be controlled, while the target temperature value for the certain zone may be a value obtained by adding a correction value to the detected temperature value corresponding to another zone.

In the heat treatment method, when the substrate holder is loaded into the reaction vessel, the heating means corresponding to the certain zone may be controlled, while a difference may be used, as the correction value, the difference being between the target temperature value set for the certain zone and the target temperature value corresponding to another zone when the substrates are subjected to a heat treatment process.

In the heat treatment method, when the substrate holder is loaded into the reaction vessel, the heating means corresponding to the certain zone may be controlled in accordance with a control signal calculated based on a value obtained by multiplying a deviation by a predetermined ratio, the deviation being between the detected temperature value of the certain zone and a target temperature value calculated by the detected temperature value corresponding to another zone or a value calculated by adding a correction value to the target temperature value.

According to the present invention, the temperature control for the certain zone follows the temperature control for another zone, when the substrates are loaded into the reaction vessel. Thus, the temperature in the reaction vessel can promptly become stable after the substrates are loaded thereinto. Thereafter, the reaction vessel is heated to a

predetermined process temperature. Then, the temperature therein can be promptly stabilized at the process temperature. The present invention can be applied to a case in which the temperatures in the respective zones, when the substrates are loaded thereinto, are the same as those in the respective zones when the substrates are processed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a longitudinal cross-sectional view of a heat treatment apparatus in an embodiment of the present invention;

Fig. 2 is a block diagram showing controlling parts and components relating thereto which are used in the embodiment;

Fig. 3 is a block diagram showing an inner structure of a first calculation part disposed in the controlling part;

Fig. 4 is a block diagram showing an inner structure of a second calculation part disposed in the controlling part;

Fig. 5 is a view illustrating a relationship between a temperature change over time and the calculation parts used in the embodiment;

Fig. 6 is a view illustrating operations of the first calculation part;

Fig. 7 is a view illustrating temperature changes of respective outer thermocouples when a wafer boat is loaded into a reaction vessel; and

Fig. 8 is a longitudinal cross-sectional view showing a general structure of a conventional heat treatment apparatus.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 is a general structure view of an embodiment in which the present invention is applied to a vertical type heat treatment apparatus. The general structure of the vertical type heat treatment apparatus is briefly described in the first place. The heat treatment apparatus includes a reaction tube 1 of a dual structure made of quartz, for example. The reaction tube 1 has an inner tube 1a having both opened ends, and an outer

tube 1b having a closed upper end. The interior of the reaction tube 1 is vertically divided into three zones Z_1, Z_2, and Z_3. A cylindrical heat insulation member 21 is secured on a base member 22 to surround the reaction tube 1. A heating mechanism 3 and a ceiling heating mechanism 31 as heating means are disposed inside the heat insulation member 21. The heating mechanism 3 and the ceiling heating mechanism 31 are formed of resistance heating elements, for example. The heating mechanism 3 is vertically divided into, for example, three heaters 3a, 3b, and 3c, and is disposed on a sidewall of the heat insulation member 21. The ceiling heating mechanism 31 is disposed on a ceiling part of the heat insulation member 21. The heaters 3a to 3c are arranged to correspond to the zones Z_1 to Z_3, respectively.

As shown in Fig. 1, the heater 3b of the heating mechanism 3 corresponding to the middle zone Z_2 serves as a main heater for forming a major part of a heat treatment atmosphere in the reaction tube 1. The heater 3a disposed above the heater 3b and the heater 3c disposed below the heater 3b are sub-heaters, and are smaller than the main heater 3b. The heaters 3a and 3c generate a heat treatment atmosphere at upper and lower parts of the reaction tube 11, respectively. The heating mechanism 3 may be manufactured by enclosing carbon wires, which are made of a plurality of knitted pure carbon fiber bundles each having a diameter of about 10 microns, in ceramics such as a transparent quartz tube having an outer diameter of about 10 mm to 20 mm. However, a material of the heating mechanism 3 is not limited thereto, and the heating mechanism 3 may be made of a metal member of, e.g., iron - tantalum - carbon alloy.

The inner tube 1a and the outer tube 1b are supported on a cylindrical manifold 23 at lower ends thereof. A gas supply tube 24 and an exhaust tube 25 are connected to the manifold 23. A gas supply opening of the gas supply tube 24 is formed in a lower region inside the inner tube 1a. The exhaust tube 25 has one end connected to a vacuum pump (not shown)

such that gases are discharged through a space between the inner tube 1a and the outer tube 1b. In this example, the inner tube 1a, the outer tube 1b, and the manifold 23 constitute a reaction vessel.

A cover 11 is disposed above a boat elevator 12 to close a lower opening of the manifold 23. A heat retention unit 13, a rotary shaft 15, and a wafer boat 16 serving as a substrate holder are disposed above the cover 11. The rotary shaft 15 passes through the heat retention unit 13 to be connected to a driving part 14 which is disposed on the boat elevator 12. A lower end of the wafer boat 16 is rotatably held by the rotary shaft 15. The wafer boat 16 is capable of holding thereon a plurality of wafers W as substrates in a tier-like manner. The heat retention unit 13 is formed by combining a heat insulation unit 13a such as a quartz fin, a heating element unit 13b, and so on.

A narrow quartz tube 40 for containing therein thermocouples is disposed in the inner tube 11a. An inner temperature detecting part 4 is disposed in the quartz tube 40. The temperature detecting part 4 has three inner thermocouples (second temperature detectors) 4a, 4b, and 4c, which are disposed correspondingly to the respective zones Z_1 to Z_3, for detecting temperatures in the respective zones Z_1, Z_2, and Z_3 heated by the respective three heaters 3a, 3b, and 3c of the heating means 3. An outer temperature detecting part 5 is disposed near the heating means 3. The outer temperature detecting part 5 has three outer thermocouples (first temperature detectors) 5a, 5b, and 5c, which are disposed correspondingly to the respective zones Z_1, Z_2, and Z_3 near the heaters 3a, 3b, and 3c of the heating means 3, for detecting the temperatures of the respective heaters 3a, 3b, and 3c of the heating means 3.

The heat treatment apparatus further includes power supply mechanism 20 for supplying power to the heating mechanism 3. The power supply mechanism 20 has power supply parts 20a, 20b, and 20c for supplying power to the

respective heaters 3a, 3b, and 3c disposed correspondingly to the respective zones Z_1, Z_2, and Z_3. The heat treatment apparatus also includes controlling parts 6, 7, and 8 for controlling powers supplied by the respective power supply parts 20a, 20b, and 20c of the power supply mechanism 20, so as to control heat generation amounts of the respective heaters 3a, 3b, and 3c of the heating means 3. Wiring structures of the respective parts, which will be described below in detail, are briefly described. The inner thermocouples 4a, 4b, and 4c of the inner temperature detecting part 4 and the outer thermocouples 5a, 5b, and 5c of the outer temperature detecting part 5 are connected to the respective controlling parts 6, 7, and 8 corresponding to the respective zones Z_1, Z_2, and Z_3. A signal wire extending from the outer thermocouple 5b disposed correspondingly to the middle zone Z_2, which is heated by the heater 3b, is branched to be connected, not only to the controlling part 7, but also to the controlling parts 6 and 8. Similar to the heaters 3a, 3b, and 3c of the heating means 3, a thermocouple 32 is provided at the ceiling heating means 31 disposed on the ceiling part of the heat insulation member 21. A power amount to be supplied from a power supply part 34 to the heating mechanism 31 is controlled by a controlling part 33, so that a heat generation amount of the heating mechanism 31 can be adjusted.

The reason for the wiring structures of the heaters 3a, 3b, and 3c of the heating mechanism 3 and the controlling parts 6, 7, and 8 connected thereto is that there are two calculation modes, which can be switched to each other, for controlling the heating mechanism 3. That is, in the former calculation mode, the heaters 3a to 3c corresponding to the respective zones Z_1 to Z_3 are independently controlled, while in the latter calculation mode, the heaters 3a and 3c are controlled to follow the temperature of the heater 3b as a main heater, by using a detected temperature value detected by the outer thermocouple 5b corresponding to the heater 3b. Referring to Fig. 2, a control system of the heating mechanism 3, which is a

characteristic feature of this embodiment, is described below.

As described above, the two calculation modes must be separately executed by each of the controlling parts 6 and 8. In order thereto, the controlling part 6 has a first calculation part 61 and a second calculation part 62, while the controlling part 8 has a first calculation part 81 and a second calculation part 82. Since it is not required for the controlling part 7 to execute both the calculation modes, the controlling part 7 has only a second calculation part 72 (the reference number 71 is not used, as a matter of convenience). The first calculation parts 61 and 81 of the respective controlling parts 6 and 8 are used for calculating control signals, when the controlling parts 6 and 8 follow the controlling part 7 (more exactly, the controlling parts 6 and 8 follow a detected temperature value obtained in the zone Z_2 corresponding to the controlling part 7). On account thereof, the branched signal wires extended from the outer thermocouple 5b are respectively connected to the first calculation part 61 of the controlling part 6 and the first calculation part 81 of the controlling part 8.

The second calculation parts 62, 72, and 82 calculates control signals based on detected temperature values detected by the inner thermocouples 4a, 4b, and 4c and the outer thermocouples 5a, 5b, and 5c, which are disposed correspondingly to the respective zones Z_1, Z_2, and Z_3, and target temperature values which are independently, exclusively set for the respective zones Z_1, Z_2, and Z_3. Thus, the inner thermocouple 4a (4b, 4c), the outer thermocouple 5a (5b, 5c) and a target value output part 63 (73, 83) are connected to the second calculation part 62 (72, 82). The control signals calculated by the first calculation parts 61 and 81, or the control signals calculated by the second calculation parts 62, 72, and 82 are output to the power supply parts 20a, 20b, and 20c of the power supply mechanism 20. The controlling part 6 (8) has a switching part 64 (84) which switches the first calculation part 61 (81) to the second calculation part 62 (82) and vice versa.

Structures of the first calculation parts 61 and 81 are

described below. Since both the calculation parts 61 and 81 have the same structure, taking the first calculation part 81 as an example, the structure thereof is described with reference to Fig. 3. In Fig. 3, the reference number 811 represents a comparison calculation part, and 812 represents a correction value output part. The comparison calculation part 811 uses as a target temperature value, a detected temperature value detected by the outer thermocouple 5b disposed correspondingly to the middle zone Z_2. The comparison calculation part 811 adds to the target temperature value, a correction value output from the correction output part 812, and subtracts therefrom a detected temperature value detected by the outer thermocouple 5c disposed correspondingly to the lowermost zone Z_3. The correction value is a static correction element for correcting a difference between the target temperature of the middle zone Z_2 and the target temperature of the lowermost zone Z_3, when the wafers W are subjected to a heat treatment process. To be specific, the correction value is obtained as a difference between the target temperature value of the middle zone Z_2 which is output from the target value output part 73 used in the second calculation part 72 and the target value of the lowermost zone Z_3 which is output from the target value output part 83 used in the second calculation part 82. The second calculation parts 72 and 82 are described below in detail.

On an output side of the comparison calculation part 811, there is provided a multiplication part 813 for multiplying an output (deviation) q1, which is output from the comparison calculation part 811, by a predetermined coefficient k. As described above, since the lowermost zone Z_3 corresponding to the controlling part 8 is located nearest the lower opening of the reaction tube 1, the lowermost zone Z_3 is most vulnerable to an influence of cooled air flowing therein together with the wafer boat 16. Thus, as compared with the middle zone Z_2, the lowermost zone Z_3 needs a larger heating output for raising the temperature therein. Taking these circumstances into

consideration, the multiplication part 813 executes a dynamic correction. That is, the multiplication part 813 multiplies the output value q1 by the predetermined coefficient k, in order to obtain an output value in which an added output from the comparison calculation part 811 is included. In the multiplication part 813, a value of the coefficient k is, for example, 1.2 (for example, 0.8 in the first calculation part 61 corresponding to the uppermost zone Z_1 which is most free from an influence of cooled air). An integral element I1, a proportion element P1, and a derivative element D1 of the obtained output value are calculated (PID calculation). Then, an output value B1 for controlling a power supply amount in accordance with the deviation q1 is output through a mixing part 814.

Structures of the second calculation parts 62, 72, and 82 are described below. Similar to the first calculation parts 61 and 81, since all the calculation parts 62, 72, and 82 have the same structure, taking the second calculation part 82 as an example, the structure thereof is described with reference to Fig. 4. The second calculation part 82 executes a cascade-control by incorporating a detected temperature value detected by the inner thermocouple 4c in a major loop, and by incorporating a detected temperature value detected by the outer thermocouple 5c in a minor loop, so as to output a control signal B2. In Fig. 4, the reference numbers 821 to 824 respectively represent comparison calculation parts, I1 represents an integral element, P2 represents a proportion element, and D1 represents a derivative element.

The controlling part 6 as described above is made of a CPU, a ROM storing therein a program, a memory in which a set temperature value is recorded, and so on. Alternatively, the controlling part 6 is operated by a software such as calculation programs. However, the calculations may be executed by a hardware in this embodiment. The switching part 84 (64) can switch the first calculation part 81 (61) to the second calculation part 82 (62) at a timing when a stable temperature in the

reaction vessel is detected before the temperature therein is raised but after the wafer boat 16 is loaded therein, or when a predetermined time passes after the wafer boat 16 is loaded in the reaction vessel. The second calculation part 82 (62) can be switched to the first calculation part 81 (61) at a timing when the temperature inside the reaction vessel is lowered at a predetermined value after the wafers W are subjected to a heat treatment process.

An operation of the above-described embodiment will be described below.

The wafers W in the heat treatment apparatus are heated by the heating mechanism 3 provided on a side of the reaction tube 1, and the ceiling heating mechanism 31 provided on an upper part thereof. Since the characteristic feature of the embodiment is a controlling method of the divided heaters 3a, 3b, and 3c of the heating mechanism 3, a description is made with reference to Fig. 5, focusing attention on the controlling method of the heating mechanism 3. At a time point t1 shown in Fig. 5, by moving the elevator 12 upward, the wafer boat 16 holding thereon the wafers W as substrates in a tier-like manner starts to be loaded in the reaction vessel (the reaction tube 1 and the manifold 23). At this time, the reaction tube 1 has been already heated at a predetermined temperature such as about 600°C. As described above, in the controlling parts 6 and 8 respectively corresponding to the uppermost and lowermost zones Z_1 and Z_3, the first operation parts 61 and 81 are selected by the switching parts 64 and 84, such that the temperatures in the uppermost and lowermost zones Z_1 and Z_3 are controlled to follow a temperature control of the middle zone Z_2.

Since the wafer boat 16 and the wafers W held thereon are located outside the reaction vessel until then, they are cooled. Thus, when an upper end of the wafer boat 16 starts to be loaded into the reaction vessel, the temperature in the lowermost zone Z_3 of the reaction vessel, which is heated by the sub-heater 3c, is once lowered. The temperature in the middle

zone Z_2 heated by the main heater 3b is also lowered under the influence of the cooled wafer boat 16. However, a lowering degree in temperature in the middle zone Z_2 is smaller than that in the lowermost zone Z_3. When the wafer boat 16 reaches the middle zone Z_2, the temperature of the middle zone Z_2 is lowered. As the wafer boat 16 and the wafers W mounted thereon are elevated in the reaction vessel, they are gradually heated. Thus, the temperature in the middle zone Z_2 becomes lower than the temperature before the wafer boat 16 is loaded thereinto, but not lower than the temperature in the lowermost zone Z_3.

After the wafer boat 16 is loaded into the reaction vessel, the lowermost zone Z_3 is the coolest zone. As compared therewith, the middle zone Z_2 is less cooler, and the uppermost zone Z_1 is the least cooled. Since a detected temperature detected by the outer thermocouple 5c is lowered, a power supply amount to the sub-heater 3c might be abruptly increased by the controlling part 8 corresponding to the lowermost zone Z_3. However, a detected temperature value in the middle zone Z_2 as a target temperature value is also lowered, the increase in the power supply amount to the sub-heater 3c is restrained in accordance with the lowering of the temperature in the middle zone Z_2. Then, accompanied with the elevation of the detected temperature value in the middle zone Z_2, the temperature of the lowermost sub-heater 3c becomes higher. Thereafter, when the temperature detected by the outer thermocouple 5b in the middle zone Z_2 overshoots the target temperature value, the temperature detected by the outer thermocouple 5b is, in turn, lowered to provide the target temperature value set for the middle zone Z_2. Following the temperature change in the middle zone Z_2, a power supply amount to the sub-heater 3c corresponding to the lowermost zone Z_3 is controlled, such that the temperature of the sub-heater 3c becomes in conformity to the target temperature value set for the lowermost zone Z_3, in response to the temperature of the sub-heater 3b in conformity to the target temperature value set for the middle zone Z_2.

Similarly, following the temperature change of the main heater 3b in the middle zone Z_2, a power supply amount to the sub-heater 3a corresponding to the uppermost zone Z_1 is controlled, such that the temperature of the sub-heater 3a becomes in conformity to the target temperature value set for the uppermost zone Z_1, in response to the temperature of the sub-heater 3b in conformity to the target temperature value set for the middle zone Z_2. As shown in Fig. 3, the temperature of the sub-heater 3c (3a) in conformity to the target temperature value set for the zone Z_3 (Z_1) is calculated by adding the correction value to the detected temperature value in the middle zone Z_2. Therefore, when the target temperature value of the lowermost zone Z_3 is set to be higher than that of the middle zone Z_2 by, e.g., 10°C during a heat treatment process of the wafers W, the temperature of the sub-heater 3c of the lowermost zone Z_3 in conformity to the target temperature value set therefor, which is higher than that of the main heater 3b by 10°C.

At a time point t2, the wafer boat 16 is completely loaded into the reaction vessel. During a period between the time points t2 and t3, the temperatures in the respective zones Z_1 to Z_3 of the reaction vessel become stable. Then, the controlling parts 6 and 8 switch the first calculation parts 61 and 81 to the second calculation parts 62 and 82, respectively, so as to control power supply amounts to the heaters 3a and 3c. At the time point t3, the reaction vessel starts to be heated to a predetermined process temperature. Then, at the time point t4 (more exactly, after the respective zones Z_1 to Z_3 are stabilized at the process temperature), the wafers W are subjected to a heat treatment process. The heat treatment is carried out as follows. For example, while the temperature in the reaction vessel is maintained at about 800°C, a predetermined film-forming gas is supplied into the reaction vessel through the gas supply tube 23. At the same time, gases in the reaction vessel are exhausted through the exhaust tube 25 to provide a vacuum of a predetermined degree, so that a film is formed on

each of the wafers W. The first calculation parts 61 and 81 can be switched to the second calculation parts 62 and 82 during the temperature in the reaction vessel is raised, or after the stable process temperature is achieved. At a time point t5, a predetermined film is formed on a surface of each of the wafers W. Then, the temperature in the reaction vessel is lowered to 600°C which is the same temperature when the wafer boat 16 is loaded into the reaction vessel. At a time point t6, the wafer boat 16 is unloaded from the reaction vessel in accordance with reverse steps when the wafer boat 16 is loaded thereinto.

As described above, in the above embodiment, in order to control the temperatures of the heaters 3a, 3b, and 3c of the heating means 3 when the wafers W are loaded into the reaction vessel, the controlling part 6 corresponding to the uppermost zone Z_1 controls the temperature therein, based on the detected temperature value of zone Z_1 by using as a target temperature value, the detected temperature value of the middle zone Z_2, while the controlling part 8 corresponding to the lowermost zone Z_3 controls the temperature therein, based on the detected temperature value of zone Z_3 by using as a target temperature value, the detected temperature value of the middle zone Z_2. Therefore, the temperatures of the respective zones Z_1 to Z_3 can be promptly stabilized at the target temperature values. For example, when the wafer boat 16 is loaded into the reaction vessel, the temperature near the sub-heater 3c of the lowermost zone Z_3 is lowered. However, since the temperature, which is the target temperature value, near the main heater 3b of the middle zone Z_2 is also lowered, a deviation between the target temperature value and the detected temperature value is diminished, and thus a heat generation amount of the sub-heater 3c can be moderately increased. Thereafter, when the temperature near the sub-heater 3c overshoots the prescribed target temperature value, the controlling part 8 controls the sub-heater 3c to decrease a heat generation amount thereof (to lower the temperature thereof). At this time, as compared with a

conventional control method in which a target temperature value is set constant, the temperature of the sub-heater 3c can be lowered in a more moderate manner, because a heat generation amount of the sub-heater 3c is controlled to follow the temperature near the main heater 3b. As a result, it is possible for the zone Z_3 to be stabilized at the target temperature value in a prompt and smooth manner, without the temperature in the zone Z_3 being drastically changed. Similarly, the temperature near the sub-heater 3a of the uppermost zone Z_1 is controlled to follow the temperature near the main heater 3b. Accordingly, the temperature in the zone Z_1 can be promptly stabilized at the target temperature value.

The first calculation parts 61 and 81 of the respective controlling parts 6 and 8 incorporate therein predetermined follow-up control ratios with respect to the controlling part 7 corresponding to the middle zone Z_2. The follow-up control ratios are determined in proportion to a degree of an influence given to the respective zones Z_1 to Z_3 by the cooled wafer boat 16 and the wafers W mounted thereon when they are loaded into the reaction vessel. In the above embodiment, for example, as compared with an influence given to the middle zone Z_2, a smaller influence is given to the uppermost zone Z_1, while a larger influence is given to the lowermost zone Z_3. Thus, the follow-up ratio incorporated in the controlling part 6 for the uppermost zone Z_1 is set to be 0.8, while the follow-up ratio incorporated in the controlling part 8 for the lowermost zone Z_3 is set to be 1.2.

Fig. 6 shows a variation of the detected temperature value detected by outer thermocouple 5b of the middle zone Z_2, and the detected temperature values of the uppermost zone Z_1 with follow-up ratios being varied at 5%, 30%, and 100%. As understood from Fig. 6, the higher the follow-up ratio is, the larger the variation of the detected temperature value detected by the outer thermocouple 5a of the uppermost zone Z_1 becomes. On the other hand, the lower the follow-up ratio is, the smaller the variation of the detected temperature value

becomes. Accordingly, by adjusting the follow-up control ratios in temperature of the sub-heaters 3a and 3c with respect to the main heater 3b, the temperatures in the uppermost zone Z_1 and the lowermost zone Z_3 can be respectively controlled in compliance with a temperature distribution in the reaction vessel when the wafer boat 16 is loaded thereinto. As a result, the temperatures in the respective zones Z_1 to Z_3 can be promptly stabilized at the target temperature values, so that a throughput can be improved. This is because the throughput is largely dependent on a period required for a stabilization of the temperatures in the respective zones Z_1 to Z_3 after the wafer boat 16 is loaded into the reaction vessel.

Fig. 7 shows changes over time in temperatures near the respective heaters 3a to 3c in the vertical heat treatment apparatus shown in Fig. 1. In this simulation, before the loading of the wafer boat 16 into the reaction vessel, the temperatures near the sub-heater 3a, the main heater 3b, and the sub-heater 3c were stabilized at 575°C, 573°C, and 560°C, respectively. Then, the wafer boat 16 was loaded into the reaction vessel. From the beginning of the loading of the wafer boat 16, it took about 13 minutes for the temperatures near the respective heaters 3a to 3c to become stable. That is, only a short time is needed for the temperatures in the respective zones Z_1 to Z_3 to become stable, when the wafers W are loaded into the reaction vessel.

In the above description of the first calculation parts 61 and 81, the output (deviation) q1 is multiplied by the predetermined constant coefficient k as a follow-up control ratio for each of the uppermost and lowermost zones Z_1 and Z_3 with respect to the middle zone Z_2. However, while the wafer boat 16 is elevated, the coefficient k may be changed in accordance with the position of the wafer boat 16. In this embodiment, when the wafers W are loaded into the reaction vessel, the controlling parts 6, 7, and 8 may read the detected temperature values detected by the inner thermocouples 4a to 4c corresponding to the respective controlling parts 6 to 8. The

controlling parts 6 (8) compares the detected temperature value detected by the inner thermocouple 4a (4c) with the detected temperature value detected by the inner thermocouple 4b of the middle zone Z_2, as a target temperature value, and controls the temperature of the sub-heater 3a (3c) in accordance with the deviation therebetween. The control part 7 controls the main heater 3b in accordance with a deviation between the exclusive target temperature value and the detected temperature value detected by the inner thermocouple 4b. Alternatively, in the embodiment, only the sub-heater 3c of the lowermost zone Z_3 is follow-up controlled by using the detected temperature value corresponding to the middle zone Z_2 as a target temperature value.

As described above, according to the present invention, when subjecting substrates in a heat treatment atmosphere which is divided into a plurality of zones, the temperatures in the respective zones can be promptly stabilized so that an improved throughput can be provided.

CLAIMS

1. A heat treatment apparatus comprising:

a reaction vessel divided into a plurality of zones;

a substrate holder to be loaded into the reaction vessel, for holding thereon a plurality of substrates;

heating means provided at the respective zones;

temperature detecting parts provided at the respective zones; and

controlling parts provided at the respective zones, for independently controlling the respective heating means; wherein

the controlling part corresponding to a certain zone includes a first calculation part for calculating a control signal, when the substrates are loaded into the reaction vessel, based on a detected temperature value detected by the temperature detecting part corresponding to the certain zone, by using as a target temperature value, a detected temperature value detected by the temperature detecting part corresponding to another zone, and outputting the control signal for controlling the corresponding heating means.

2. The heat treatment apparatus according to claim 1, wherein

each of the temperature detecting part includes a first temperature detector for detecting a temperature near the corresponding heating means, and the detected temperature value detected by the temperature detecting part corresponding to another zone is a detected temperature value detected by the first temperature detector.

3. The heat treatment apparatus according to claim 1, wherein

each of the temperature detecting part includes a second temperature detector for detecting a temperature in the corresponding zone of the reaction vessel, and the detected

temperature value detected by the temperature detecting part corresponding to another zone is a detected temperature value detected by the second temperature detector.

4. The heat treatment apparatus according to claim 1, wherein

the controlling part corresponding to the certain zone further includes a second calculation part for calculating a control signal, when the substrates are subjected to a heat treatment process, based on the target temperature value set for the certain zone and the detected temperature value detected by the temperature detecting part corresponding to the certain zone, and outputting the control signal for controlling the corresponding heating means.

5. The heat treatment apparatus according to claim 1, wherein

each of the temperature detecting part includes the first temperature detector for detecting a temperature near the corresponding heating means, and the second temperature detector for detecting a temperature in the corresponding zone of the reaction vessel,

the first calculation part of the controlling part corresponding to the certain zone calculates a control signal, when the substrates are loaded into the reaction vessel, by using as a target temperature value, the detected temperature value detected by the first temperature detector or the second temperature detector corresponding to another zone, and outputs the control signal for controlling the corresponding heating means, and

the controlling part corresponding to the certain zone further includes the second calculation part for calculating a control signal, when the substrates are subjected to a heat treatment process, based on the target temperature values set for the certain zone and the respective detected temperature values detected by the first temperature detector and the

second temperature detector corresponding to the certain zone, and outputting the control signal for controlling the corresponding heating means.

6. The heat treatment apparatus according to claim 1, wherein

the first calculation part of the controlling part corresponding to the certain zone calculates the control signal based on a deviation between a value obtained by adding a correction value to the detected temperature value detected by the temperature detecting part corresponding to another zone and the detected temperature value detected by the temperature detecting part corresponding to the certain zone, and outputs the control signal for controlling the corresponding heating means.

7. The heat treatment apparatus according to claim 6, wherein

when the substrates are subjected to a heat treatment process, the first calculation part of the controlling part corresponding to the certain zone uses as the correction value, a difference between the target temperature value set for the certain zone and the target temperature value corresponding to another zone.

8. The heat treatment apparatus according to claim 6, wherein

the first calculation part of the controlling part corresponding to the certain zone calculates the control signal, based on a value obtained by multiplying the deviation between a value obtained by adding the correction value to the detected temperature value detected by the temperature detecting part corresponding to another zone and the detected temperature value detected by the temperature detecting part corresponding to the certain zone, by a predetermined ratio.

9. The heat treatment apparatus according to claim 1, wherein

the reaction vessel is of a vertical type and the substrate holder is loaded into the reaction vessel from a lower part thereof,

the reaction vessel is vertically divided into at least three zones in which the certain zone is a lowermost zone and another zone is a zone other than an uppermost one.

10. A heat treatment method for subjecting substrates to a heat treatment, by loading a substrate holder holding thereon a plurality of substrates into a reaction vessel divided into a plurality of zones, and heating the plurality of zones by heating means respectively corresponding thereto, comprising the steps of:

detecting a temperature value corresponding to each of the zones; and

controlling each of the heating means based on a target temperature value and the detected temperature value of the corresponding zone; wherein

when the substrate holder is loaded into the reaction vessel, the heating means corresponding to a certain zone is controlled by using, as the target temperature value for the certain zone, a detected temperature value corresponding to another zone.

11. The heat treatment method according to claim 10, wherein

when the substrate holder is loaded into the reaction vessel, the heating means corresponding to the certain zone is controlled, while the target temperature value for the certain zone is a value obtained by adding a correction value to the detected temperature value corresponding to another zone.

12. The heat treatment method according to claim 11, wherein

when the substrate holder is loaded into the reaction vessel, the heating means corresponding to the certain zone is controlled, while a difference is used, as the correction value, the difference being between the target temperature value set for the certain zone and the target temperature value corresponding to another zone when the substrates are subjected to a heat treatment process.

13. The heat treatment method according to claim 10, wherein

when the substrate holder is loaded into the reaction vessel, the heating means corresponding to the certain zone is controlled in accordance with a control signal calculated based on a value obtained by multiplying a deviation by a predetermined ratio, the deviation being between the detected temperature value of the certain zone and a target temperature value calculated by the detected temperature value corresponding to another zone or a value calculated by adding a correction value to the target temperature value.