HEAT TREATMENT METHOD AND APPARATUS THEREFOR

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a heat treatment method and an apparatus therefor.

Background Art

In a manufacturing process of a semiconductor device, various heat treatment apparatuses are used for subjecting a semiconductor wafer, as an object to be processed to treatments such as an oxidation, a diffusion, and a film-forming. For example, a batch type vertical heat treatment apparatus has been known, in which a plurality of objects to be processed can simultaneously be subjected to a heat treatment.

In such a vertical heat treatment apparatus, a holder vertically mounts thereon a plurality of objects to be processed with a predetermined gap therebetween, and is loaded into a processing vessel. The objects to be processed are subjected to a predetermined heat treatment by using a tubular heater disposed around the processing vessel. The tubular heater heats the objects to be processed at a heat generation amount which is set based on temperature data detected by a temperature sensor disposed in the processing vessel.

When semiconductor wafers are subjected to a heat treatment, both a high intrafilm uniformity in the temperature of each of the semiconductor wafers and a high interfilm uniformity in the temperature among the semiconductor wafers at different vertical levels are needed, so as to achieve a uniform film quality and desired features of each film. In order to meet such requirements, the inside of the processing vessel is vertically divided into a plurality of heating zones, and objects to be processed disposed in each of the heating zones are heated at a corresponding heat generation amount.

In the heat treatment apparatus as constituted above, the temperature sensor includes a straight, vertically extending

protective tube made of, e.g., quartz glass, and thermo-couples provided within the protective tube at positions corresponding to the respective heating zones of the processing vessel. The thermo-couples of the temperature sensor detect temperatures at positions corresponding to the respective heating zones of the processing vessel. Then, a heat generation amount of the tubular heater is adjusted based on the detected temperature data.

In the vertical heat treatment apparatus, the temperature is detected at a position away from the semiconductor wafer, which inevitably results in a discrepancy between the temperature detected by the temperature sensor and the actual temperature of the semiconductor wafer. Thus, it is difficult to accurately control a temperature of the tubular heater.

SUMMARY OF THE INVENTION

The present invention has been made in view of the above circumstances. An object of the present invention is to provide a heat treatment method which can detect a temperature of an object to be processed with high precision, so that the object to be processed can be stably subjected to a desired heat treatment, and an apparatus for securely carrying out the heat treatment method.

The present invention is a heat treatment method for subjecting an object to be processed to a predetermined heat treatment, comprising the steps of: loading into a processing vessel a holder vertically holding a plurality of objects to be processed with a predetermined gap therebetween; and operating heating means disposed on the processing vessel to generate a target heat generation amount, so as to heat the objects to be processed; wherein the heating means is operated to generate the target heat generation amount which is obtained by the following steps (1) to (3),

(1) after operating the heating means to generate a reference heat generation amount which is set such that the objects to be processed have a target heating temperature,

detecting a controlled temperature of the objects to be processed by a first temperature sensor for controlling a temperature which is vertically extended in the processing vessel;

(2) detecting a target controlled temperature of the objects to be processed by a second temperature sensor for correcting a temperature which is interposed between the objects to be processed; and

(3) comparing the controlled temperature of the objects to be processed detected by the first temperature sensor, with the target controlled temperature detected by the second temperature sensor, and correcting the reference heat generation amount based on a temperature difference between the target controlled temperature and the controlled temperature, so as to decide the target heat generation amount.

In the heat treatment method, when the target heat generation amount is obtained, the controlled temperature may be detected by the first temperature sensor, in a condition where the controlled temperature becomes substantially stable after the heating means is operated to generate the reference heat generation amount.

In the heat treatment method, when the target heat generation amount is obtained, the temperature of the objects to be processed may be detected by the second temperature sensor interposed between the objects to be processed at different vertical levels.

In the heat treatment method, when the target heat generation amount is obtained, the temperature of the objects to be processed may be detected by the second temperature sensor at center parts of the objects to be processed.

In the heat treatment method, when the target heat generation amount is obtained, the temperature of the objects to be processed may be detected by the second temperature sensor at center parts and edge parts of the objects to be processed.

In the heat treatment method, the objects to be treated may be subjected to a heat treatment, without the second temperature sensor being arranged between the objects to be processed.

The present invention is a heat treatment apparatus comprising: a processing vessel; a holder to be loaded into the processing vessel, the holder vertically holding a plurality of objects to be processed in horizontal postures with a predetermined gap therebetween; heating means disposed outside the processing vessel; a first temperature sensor for controlling a temperature disposed in the processing vessel, for detecting a controlled temperature which is referred to for controlling a heat generation amount of the heating means such that the objects to be processed have a target heating temperature at which the objects to be processed are subjected to a heat treatment; and a second temperature sensor for correcting a temperature disposed in the processing vessel, for detecting a target controlled temperature substantially corresponding to the target heating temperature, which is referred to for correcting the heat generation amount of the heating means; wherein the heat generation amount of the heating means is corrected by a control part based on the target controlled temperature detected by the second temperature sensor, and the controlled temperature detected by the first temperature sensor.

Herein, the phrase "substantially corresponding to" means that a temperature difference between the target controlled temperature and the target heating temperature is in a range within ± 0.5°C to ± 1.0°C.

In the heat treatment apparatus, the second temperature sensor may include a straight, vertically extending protective tube body, and a plurality of branch tubes being vertically spaced apart from each other, each of the branch tubes extending from the protective tube body in a direction perpendicular to an axis of the protective tube body, thermo-couples may be provided within the branch tubes

respectively, and the branch tubes may be interposed between the objects to be processed at different vertical levels.

In the heat treatment apparatus, the protective tube body of the second temperature sensor can be rotated about its axis.

In the heat treatment apparatus, an annular groove may be formed on a circumference of a proximal end portion of the protective tube body of the second temperature sensor.

In the heat treatment apparatus, the interior within the protective tube body and the branch tubes may be in a negative pressure, and the proximal end portion of the protective tube body may be air-tightly sealed.

The present invention is a temperature sensor for correcting a temperature, comprising: a straight, vertically extending protective tube body; and a plurality of branch tubes being vertically spaced apart from each other, each of the branch tubes extending from the protective tube body in a direction perpendicular to an axis of the protective tube body; wherein thermo-couples are provided within the branch tubes respectively, and the branch tubes are interposed between objects to be processed at different vertical levels.

According to the present invention, in order to subject the objects to be processed to a heat treatment, the target heat generation amount is obtained beforehand. In this obtaining step, the temperature of the objects to be processed can be detected with high precision by the second temperature sensor interposed between the objects to be processed. Then, the reference heat generation amount of the heating means is corrected based on a temperature difference between the target controlled temperature detected by the second temperature sensor and the controlled temperature detected by the first temperature sensor, such that the target controlled temperature detected by the second temperature sensor substantially corresponds to a target heating temperature at which the objects to be processed should be subjected to a heat treatment. Therefore, a heat generation amount of the heating means can

be accurately controlled.

In addition, the second temperature sensor includes the protective tube body and the plurality of branch tubes in which the thermo-couples are respectively provided. Thus, the temperature of the objects to be processed can be detected, without metal contaminations and particles adhering on the objects to be processed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an illustrational cross-sectional view schematically showing a structure of an example of a heat treatment apparatus according to the present invention;

Fig. 2 is an illustrational cross-sectional view showing a structure of an example of a first temperature sensor for controlling a temperature;

Fig. 3 is an illustrational cross-sectional view showing a structure of an example of a second temperature sensor for correcting a temperature;

Fig. 4 is an illustrational cross-sectional view showing an example of a sealing structure of the second temperature sensor shown in Fig. 3; and

Fig. 5 is a graph showing changes over time of a temperature of semiconductor wafers, a temperature detected by the first temperature sensor, and a temperature detected by the second temperature sensor, when their temperatures are in a stable condition.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will be described hereinbelow with reference to the drawings, taking a vertical heat treatment apparatus as an example in which an object to be processed is subjected to a film-forming process by a CVD method.

Fig. 1 is an illustrational cross-sectional view schematically showing a structure of an example of a heat treatment apparatus according to the present invention.

The vertical heat treatment apparatus includes a

processing vessel (processing tube) 11 of a dual tube structure. The processing vessel 11 has a straight inner tube 11A extended in a height direction (vertical direction in Fig. 1), and an outer tube 11B disposed concentrically around the inner tube 11A with a predetermined gap therebetween. An upper end of the inner tube 11A is opened, while an upper end of the outer tube 11B is closed. A lower space of the processing vessel 11 provides a loading area L in which a semiconductor wafer as an object to be processed is loaded to and/or unloaded from a wafer boat 17 for holding the object to be processed, which is described below.

The inner tube 11A and the outer tube 11B are made of a material having superior heat resistance and corrosion resistance, such as pure quartz glass.

A short, cylindrical manifold 12 having a flange part 12A at its upper end is disposed on a lower end part of the outer tube 11B of the processing vessel 11. A lower end flange part 111 is disposed on the lower end part of the outer tube 11B. The lower end flange part 111 is joined to the flange part 12A by a flange pusher 13 through sealing means (not shown) such as an O-ring, so that the outer tube 11B of the processing vessel 11 is secured to the flange portion 12A.

The inner tube 11A of the processing vessel 11 is downwardly extended from a lower end surface of the outer tube 11B, and is inserted to the manifold 12. In this state, the inner tube 11A is supported by an annular inner tube support part 14 formed on an inner surface of the manifold 12.

In a vertical cross-section of the processing vessel 11 of the vertical heat treatment apparatus, a gas supply pipe 15 for introducing a process gas and an inert gas into the processing vessel 11 is disposed on one sidewall of the manifold 12. The gas supply pipe 15 passes air-tightly through the sidewall of the manifold 12 and extends upwardly in the inner tube 11A. A gas supply source (not shown) is connected to the gas supply pipe 15.

An exhaust system 16 for discharging air in the

processing vessel 11 is disposed on the other sidewall of the manifold 12. An exhaust mechanism (not shown) having, for example, a vacuum pump and a pressure control mechanism is connected to the exhaust system 16. The exhaust mechanism controls a pressure in the processing vessel 11 at a predetermined value.

An elevating mechanism 21 is disposed below the processing vessel 11. The elevating mechanism 21 is vertically driven to load the wafer boat 17 as a holder for holding an object to be processed into the processing vessel 11, and to unload the wafer boat 17 therefrom. The elevating mechanism 21 has a disk-shaped cover 20 for opening and closing a lower opening 11C of the processing vessel 11.

The wafer boat 17 is made of, e.g., pure quartz glass. A plurality of, for example, about 100 to 150 pieces of semiconductor wafers in horizontal postures are mounted on the wafer boat 17 in a tier-like manner with a predetermined vertical gap (pitch) of, e.g., 5.2 mm to 20.8 mm between the semiconductor wafers.

A columnar support member 22, which is extended upward in parallel with the processing vessel 11, is disposed to pass through the cover 20 of the elevating mechanism 21. A disk-shaped boat support 22A on which the wafer boat 17 is mounted is integrally disposed on the support member 22 which is connected to rotation driving means 23 disposed below the cover 20.

A heat-insulating tube 24 made of, e.g., quartz is disposed above the cover 20, with the support member 22 passing through the heat-insulating tube 24.

A tubular heater 30 is disposed outside the processing vessel 11 to surround the same. The tubular heater 30 serves as heating means for heating the semiconductor wafers contained in the processing vessel 11 at a predetermined treatment temperature.

The tubular heater 30 includes a cylindrical heat insulating material (not shown). On an inner surface of the

heat insulating material, there is provided a linear resistance heating element arranged in a spiral or meandering way. The resistance heating element is connected to a control part 31. The control part 31 controls a power supplied to the heating means, based on temperature data of the semiconductor wafers detected by a first temperature sensor 40 which is described below, such that the semiconductor wafers have a previously set temperature.

The processing vessel 11 is vertically divided into a plurality of, for example, three heating zones Z1 to Z3 in Fig. 1. The tubular heater 30 heating the heating zones Z1 to Z3 individually is controlled by the control part 31. That is, the temperatures in the respective heating zones Z1 to Z3 are zone-controlled by the tubular heater 30.

A surface heater 32 is disposed on an upper part of the processing vessel 11, in a manner where the surface heater 32 is arranged in opposition to the wafer boat 17 in the processing vessel 11, and in parallel with an upper end surface of the tubular heater 30. The surface heater 32 effectively prevents heat release from the upper part of the processing vessel 11. Thus, each of the semiconductor wafers can be subjected to a heat treatment with a high intrafilm uniformity.

The surface heater 32 has a linear resistance heating element which is arranged on a plate-like substrate and is connected to the control part 31.

The first temperature sensor 40 for controlling a temperature (hereinafter simply referred to as "first temperature sensor") for detecting a controlled temperature of the semiconductor wafers is disposed in the processing vessel 11 of the vertical heat treatment apparatus. A value detected by the first temperature sensor 40 is referred to for controlling a heat generation amount of the tubular heater 30 and the surface heater 32, such that the semiconductor wafers have a target heating temperature.

To be specific, the first temperature sensor 40 passing air-tightly through a lower wall of the manifold 12 is extended in

a direction in parallel with the inner tube 11A, within substantially an annular space formed between the wafer boat 17 loaded in a predetermined position in the processing vessel 11 and the inner tube 11A. A distal end part of the first temperature sensor 40 extending from an upper end surface of the inner tube 11A is extended toward a center part of the processing vessel 11, in parallel with the semiconductor wafers held by the wafer boat 17.

As shown in Fig. 2, the first temperature sensor 40 made of, e.g., transparent quartz glass includes a protective tube 41 which is bent into substantially an L-shape, with a distal end part thereof extending in a horizontal direction (right direction in Fig. 2), and a plurality of (four in total in this embodiment) thermo-couples 42 provided within the protective tube 41. One of the thermo-couples 42 is arranged on a position corresponding to a heating zone heated by the surface heater 32 (for example, a position corresponding to the center part of the surface heater 32). The rest three thermo-couples 42 are arranged on positions respectively corresponding to the heating zones Z1 to Z3 heated by the tubular heater 30.

The protective tube 41 has a closed distal end portion and a proximal end portion which is sealed by a sealing material 45 such as an adhesive. Metal wires of the thermo-couples 42 are led outside through the sealed proximal end portion, and are connected to input terminals of the control part 31 through compensating lead wires.

The proximal end portion of the protective tube 41 may be air-tightly sealed. In order to prevent the thermo-couples 42 from being oxidized, the protective tube 41 may be filled with an inert gas such as a nitrogen gas (N_2 gas).

The metal wires of the thermo-couples 42 are respectively inserted in insulating members 44 made of, e.g., alumina ceramics. Each of the insulating members 44 has a plurality of sleeve-like beads 44A each being 3 mm in length, for example. The beads 44A are continuously arranged in a longitudinal direction thereof. In Fig. 2, the insulating

members 44 are shown as a single insulating member, as a matter of simplicity.

A second temperature sensor 50 for correcting a temperature (hereinafter simply referred to as "second temperature sensor 50") for detecting a target controlled temperature of the semiconductor wafers is disposed in the processing vessel 11 of the vertical heat treatment apparatus. The target controlled temperature of the semiconductor wafers, which is substantially corresponding to the target heating temperature, is referred to for correcting the reference heat generation amount of the tubular heater 30 and the surface heater 32.

As shown in Fig. 3, the second temperature sensor 50 includes a protective tube body 52, and a first branch tube 53A horizontally extending from a distal end portion of the protective tube body 52. The protective tube body 52 and the branch tube 53A form substantially an L-shape. The second temperature sensor 50 further includes a plurality of (two shown in Fig. 3) branch tubes 53B and 53C which are vertically spaced apart from the branch tube 53A, and are horizontally extended from the protective tube body 52 in a direction perpendicular to an axis of the protective tube body 52. Thermo-couples 54 are provided within the respective branch tubes 53A, 53B, and 53C at distal end portions thereof. The protective tube body 52 and the branch tubes 53A, 53B, and 53C together form a protective tube 51.

Metal wires of the thermo-couples 54 are respectively inserted in insulating members 56 made of, e.g., alumina ceramics. Each of the insulating members 56 has a plurality of sleeve-like beads 56A each being 3 mm in length, for example. The beads 56A are continuously arranged in a longitudinal direction thereof.

The distal end portions of the respective branch tubes 53A, 53B, and 53C are closed. A proximal end portion of the protective tube body 52 is sealed. The metal wires of the thermo-couples 54 are led outside through the sealed proximal

end portion, and are connected to input terminals of the control part 31 through compensating lead wires.

The proximal end portion of the protective tube body 52 may be air-tightly sealed. In order to prevent the thermo-couples 54 from being oxidized, the protective tube 51 may be filled with an inert gas such as a nitrogen gas (N_2 gas).

To be specific, as shown in Fig. 4, a proximal end portion of the protective tube 51 is filled with a sealing material 57 such as cement to form an air-tightly sealing structure. An end structure 60 is disposed on the proximal end portion of the protective tube 51 to continuously extend outward therefrom. An insulating member 56 is inserted to the end structure 60. The end structure 60 includes an assisting tube 61 made of, e.g., quartz glass which has a thermal contraction tube 62 disposed on its inner surface, and a sleeve-like insulating member 63 made of, e.g., Teflon® which is inserted to the assisting tube 61.

An annular groove 58 is formed on a circumference of the proximal end portion of the protective tube body 52 of the protective tube 51, more specifically, on a boundary part of the protective tube body 52 between interior and exterior sides of the processing vessel 11. By fitting the lower wall of the manifold 12 in the annular groove 58, the second temperature 50 is positioned in the processing vessel 11.

Before the semiconductor wafers are subjected to a predetermined heat treatment, the second temperature sensor 50 is used for obtaining a target heat generation amount of the tubular heater 32 (for carrying out an operation for obtaining a target heat generation amount).

The second temperature sensor 50 can be rotated about an axis of the upwardly extending protective tube body 52. In order to carry out the operation for obtaining a target heat generation amount, the protective tube body 52 is rotated about its axis, so that the branch tubes 53A, 53B, and 53C are respectively interposed between the semiconductor wafers held by the wafer boat 17, which are located at vertically corresponding positions to the branch tubes 53A, 53B, and 53C.

It is preferable that the respective branch tubes 53A, 53B, and 53C are interposed between the semiconductor wafers at different vertical levels. In addition, it is preferable that the thermo-couples 54, which are disposed at the distal end portions of the respective branch tubes 53A, 53B, and 53C, reach points corresponding to center parts of the semiconductor wafers.

Alternatively, thermo-couples may be arranged such that temperatures at the center parts and edge parts of the semiconductor wafers can be simultaneously measured.

In the embodiment shown in the drawings, the first branch tube 53A extending from an upper end of the protective tube 51 in a horizontal direction (left direction in Fig. 3) is positioned on an upper space of an uppermost one of the semiconductor wafers to be processed. The lowest third branch tube 53C of the second temperature sensor 50 is positioned on an upper space of a lowermost one of the semiconductor wafers to be processed. The second branch tube 53B, which is located vertically between the first branch tube 53A and the third branch tube 53C, is positioned on an upper space of a central one of the semiconductor wafers to be processed.

A heat treatment method for semiconductor wafers carried out in the vertical heat treatment apparatus as constituted above will be described below.

First, semiconductor wafers are transferred to the wafer boat 17 in the loading area L. The wafer boat 17 holding therein the semiconductor wafers is mounted on the boat support 22A. In this state, the cover 20 is located on a lowermost position. Then, the cover 20 is upwardly driven by the elevating mechanism 21, so that the wafer boat 17 is loaded into the processing vessel 11 through the lower opening 11C. Next, the lower opening 11C of the processing vessel 11 is air-tightly closed by the cover 20. By operating the exhaust means, the pressure in the processing vessel 11 is reduced to a predetermined value such as about 6×10^{-4} Pa. Imitational semiconductor wafers (dummy wafers) are mounted on, for

example, uppermost and lowermost stages of the wafer boat 17.

Subsequently, the operation for obtaining a target heat generation amount is carried out so as to decide a target heat generation amount of the tubular heater 30 and the surface heater 32. Firstly, the second temperature sensor 50 is rotated about the axis of the protective tube body 52, so that the respective branch tubes 53A, 53B, and 53C are interposed between the semiconductor wafers at different vertical levels. Then, while a controlled temperature is detected by the first temperature sensor 40, the tubular heater 30 and the surface heater 32 are operated to generate the reference heat generation amount such that the semiconductor wafers have a predetermined target heating temperature.

After the controlled temperature detected by the first temperature sensor 40 becomes substantially stable, the first temperature sensor 40 continues the temperature detection.

Herein, the "substantially stable" condition means that a variation of the controlled temperature detected by the first temperature 40 is within a range of, e.g., ± 0.5°C to 1.0°C. After more than an hour passes from the beginning of operating the tubular heater 30 and the surface heater 32, the controlled temperature generally becomes stable in a satisfactory manner.

The controlled temperature detected by the respective thermo-couples 42 of the first temperature sensor 40, and the target controlled temperature detected by the respective thermo-couples 54 of the second temperature sensor 50 are input to the control part 31. When the target controlled temperature detected by the second temperature sensor 50 substantially corresponds to the target heating temperature at which the semiconductor wafers should be heated, temperature data at corresponding vertical levels are compared to each other by the control part 31.

On the other hand, when the target controlled temperature detected by the second temperature sensor 50 does not substantially correspond the target heating

temperature at which the semiconductor wafers should be heated, the reference heat generation amount of the tubular heater 30 and the surface heater 32 are reset by the control part 31, and the above steps are repeated.

For example, the control part 31 decides a target heat generation amount of the tubular heater 30 which heats the semiconductor wafers positioned in the heating zone Z1, based on a temperature difference between the target controlled temperature detected by the second temperature sensor 50 and the controlled temperature detected by the first temperature sensor 40.

The same operation as above is carried out for the semiconductor wafers positioned in the heating zones Z2 and Z3.

Thereafter, the second temperature sensor 50 is rotated such that the branch tubes 53A, 53B, and 53C are withdrawn from between the semiconductor wafers. Then, with the wafer boat 17 being rotated by the rotation driving means 23, a suitable treatment gas is introduced from the gas supply pipe 15 into the processing vessel 11, so that the semiconductor wafers are subjected to a film-forming process.

In the above-described vertical heat treatment apparatus, in order to subject the semiconductor wafers to a heat treatment, the target heat generation amount is obtained beforehand. In this obtaining step, the temperature of the semiconductor wafers can be detected with high precision by the second temperature sensor 50. Accordingly, the reference heat generation amount can be corrected based on a temperature difference between the target controlled temperature detected by the second temperature sensor 50 and the controlled temperature detected by the first temperature sensor 40, such that the target controlled temperature detected by the second temperature sensor 50 substantially corresponds to the target heating temperature at which the semiconductor wafers should be subjected to a heat treatment. Since the heat generation amount of the tubular heater 30 and the surface

heater 32 can be accurately controlled, a desired heat treatment can be stably carried out for the semiconductor wafers.

After the temperature detected by the first temperature sensor 40 becomes stable, the operation for obtaining a target heat generation amount is carried out. Therefore, it is possible to securely obtain an accurate temperature difference between the target controlled temperature detected by the second temperature sensor 50 and the controlled temperature detected by the first temperature sensor 40. As a result, the heat generation amount of the tubular heater 30 and the surface heater 32 can be controlled with precision.

Since the respective branch tubes 53A, 53B, and 53C of the second temperature sensor 50 are interposed between the semiconductor wafers at different vertical levels, the temperatures at different vertical levels can be independently controlled. Consequently, in an actual heat treatment of the semiconductor wafers, all the semiconductor wafers can be subjected to substantially a uniform heat treatment at a desired temperature, irrespective of the vertical positions of the semiconductor wafers.

The thermo-couples 54, 54, and 54, which are disposed at the distal end portions of the respective branch tubes 53A, 53B, and 53C reach points corresponding to the center parts of the semiconductors. Accordingly, substantially only emitted lights from the semiconductor wafers can be detected, which results in a temperature detection of the semiconductor wafers with high precision.

The thermo-couples 54, 54, and 54 of the second temperature sensor 50 are provided within the respective branch tubes 53A, 53B, and 53C. That is, the metal wires or the like of the thermo-couples 54 are not exposed to an atmosphere in the processing vessel 11, which securely prevents metal contaminations and particles from adhering on the semiconductor wafers. Thus, there is no need for quartz tools to be changed or cleaned after the target heat generation is set, which may be necessary when a temperature of the

semiconductor wafers is detected by directly disposing a thermo-couple thereon. Accordingly, a desired heat treatment can be advantageously carried out for the semiconductor wafers.

By being fitted in the manifold 12, the annular groove 58 formed on the circumference of the proximal end portion of the protective tube 51 can serve as a stopper. Thus, when a pressure in the processing groove 11 is reduced, the second temperature sensor 50 can be securely prevented from being drawn into the processing vessel 11.

In the above embodiment, the protective tube 51 of the second temperature sensor 50 is in an inert gas atmosphere. However, the interior of the protective tube 51 may be in a negative pressure, and the proximal end portion of the protective tube 51 may be air-tightly sealed.

In this structure, if the protective tube 51 is broken for some reason when the processing vessel 11 is decompressed, fragments of the broken protective tube 51 can be securely prevented from scattering in the processing vessel 11.

Also in the first temperature sensor 40, the inside of the protective tube 41 may be in a negative pressure, and the proximal end portion of the protective tube 41 may be air-tightly sealed.

EXAMPLE

An experiment conducted by using the vertical heat treatment apparatus having a constitution shown in Fig. 1 will be described below.

Twenty-five pieces of semiconductor wafers each having a diameter of 200 mm were vertically mounted on a wafer boat 17 in a tier-like manner at pitches of 15.6 mm, with dummy wafers being mounted on uppermost and lowermost stages of the wafer boat 17. The wafer boat 17 was loaded into a processing vessel 11. Then a tubular heater 30 and a surface heater 32 were operated to generate a reference heat generation amount which was set such that all the semiconductor wafers had a

temperature of 800°C (target heating temperature). After two hours had passed from the beginning of heating, a first temperature sensor 40 for controlling a temperature and a second temperature sensor 50 for correcting a temperature were operated. A controlled temperature detected by the first temperature sensor 40 was 800°C, and a target controlled temperature detected by the second temperature sensor 50 was 803°C.

Then, a target heat generation amount was set by correcting the reference heat generation amount, based on a temperature difference of 3°C between the target controlled temperature and the controlled temperature, in order that the controlled temperature became 798°C. Thereafter, the tubular heater 30 and the surface heater 32 were operated to generate the set target heat generation amount. As a result, the target controlled temperature detected by the second temperature 50 became 800°C, so that all the semiconductor wafers could be subjected to a desired heat treatment. Fig. 5 is a graph showing changes over time of a temperature of semiconductor wafers, a temperature detected by the first temperature sensor 40, and a temperature detected by the second temperature sensor 50, when their temperatures are in a stable condition.

The embodiment of the present invention has been described above. However, the present invention is not limited to the embodiment, and various changes and modification can be made within the scope of the present invention.

For example, the number of the branch tubes of the second temperature sensor, positions to which the branch tubes are inserted, and other structure are not particularly limited. They may be suitably changed in accordance with the number and dimensions (outer diameter size) of objects to be processed which are simultaneously treated.

In the above embodiment, the branch tubes of the second temperature sensor are positioned such that the branch tubes respectively correspond to the heating zones heated by the tubular heater. However, they are not necessarily

positioned to correspond to the heating zones heated by the tubular heater.

The thermo-couples are disposed at the distal end portions of the branch tubes. However, the number and the disposed positions of the thermo-couples are not limited. For example, a plurality of thermo-couples may be horizontally disposed to be spaced apart from each other in one branch tube. More specifically, the thermo-couples are positioned such that their ends can reach a center part and an edge part of a wafer.

In addition, the operation for obtaining a target heat generation amount may be carried out, not for semiconductor wafers which are actually subjected to a heat treatment, but for imitational objects to be processed (dummy wafers).

In the above embodiment, the first temperature sensor 40 is disposed in the inner tube 11A. However, the first temperature sensor 40 may be disposed to pass through the heaters 30 and 32 to detect a temperature thereof.

Not limited to a film-forming process, the present invention may be applied to a heat treatment apparatus in which processes such as oxidation, diffusion, and annealing are carried out.

In the heat treatment method according to the present invention, in order to subject the objects to be processed to a heat treatment, the target heat generation amount is obtained beforehand. In this obtaining step, the temperature of the objects to be processed can be detected with high precision by the second temperature sensor interposed between the objects to be processed. Accordingly, the reference heat generation amount can be corrected based on a temperature difference between the target controlled temperature detected by the second temperature sensor and the controlled temperature detected by the first temperature sensor, such that the target controlled temperature detected by the second temperature sensor substantially corresponds to the target heating temperature at which the objects to be processed should be subjected to a heat treatment. Since the heat generation

amount of the heating means can be accurately controlled, a desired heat treatment can be stably carried out for the objects to be processed.

In the heat treatment apparatus according to the present invention, since the above heat treatment method can be securely carried out, a temperature of the objects to be processed can be detected with high precision. As a result, a heat generation amount of the heating means can be accurately controlled, and thus the objects to be processed can be stably subjected to a desired heat treatment.

CLAIMS

1. A heat treatment method for subjecting an object to be processed to a predetermined heat treatment, comprising the steps of:

loading into a processing vessel a holder vertically holding a plurality of objects to be processed with a predetermined gap therebetween; and

operating heating means disposed on the processing vessel to generate a target heat generation amount, so as to heat the objects to be processed; wherein

the heating means is operated to generate the target heat generation amount which is obtained by the following steps (1) to (3),

(1) after operating the heating means to generate a reference heat generation amount which is set such that the objects to be processed have a target heating temperature, detecting a controlled temperature of the objects to be processed by a first temperature sensor for controlling a temperature which is vertically extended in the processing vessel;

(2) detecting a target controlled temperature of the objects to be processed by a second temperature sensor for correcting a temperature which is interposed between the objects to be processed; and

(3) comparing the controlled temperature of the objects to be processed detected by the first temperature sensor, with the target controlled temperature detected by the second temperature sensor, and correcting the reference heat generation amount based on a temperature difference between the target controlled temperature and the controlled temperature, so as to decide the target heat generation amount.

2. The heat treatment method according to claim 1, wherein when the target heat generation amount is obtained, the

controlled temperature is detected by the first temperature sensor, in a condition where the controlled temperature becomes substantially stable after the heating means is operated to generate the reference heat generation amount.

3. The heat treatment method according to claim 1, wherein when the target heat generation amount is obtained, the temperature of the objects to be processed is detected by the second temperature sensor interposed between the objects to be processed at different vertical levels.

4. The heat treatment method according to claim 1, wherein when the target heat generation amount is obtained, the temperature of the objects to be processed is detected by the second temperature sensor at center parts of the objects to be processed.

5. The heat treatment method according to claim 1, wherein when the target heat generation amount is obtained, the temperature of the objects to be processed is detected by the second temperature sensor at center parts and edge parts of the objects to be processed.

6. The heat treatment method according to claim 1, wherein the objects to be treated are subjected to a heat treatment, without the second temperature sensor being arranged between the objects to be processed.

7. A heat treatment apparatus comprising:

a processing vessel;

a holder to be loaded into the processing vessel, the holder vertically holding a plurality of objects to be processed in horizontal postures with a predetermined gap therebetween;

heating means disposed outside the processing vessel;

a first temperature sensor for controlling a temperature disposed in the processing vessel, for detecting a controlled

temperature which is referred to for controlling a heat generation amount of the heating means such that the objects to be processed have a target heating temperature at which the objects to be processed are subjected to a heat treatment; and

a second temperature sensor for correcting a temperature disposed in the processing vessel, for detecting a target controlled temperature substantially corresponding to the target heating temperature, which is referred to for correcting the heat generation amount of the heating means; wherein

the heat generation amount of the heating means is corrected by a control part based on the target controlled temperature detected by the second temperature sensor, and the controlled temperature detected by the first temperature sensor.

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

the second temperature sensor includes a straight, vertically extending protective tube body, and a plurality of branch tubes being vertically spaced apart from each other, each of the branch tubes extending from the protective tube body in a direction perpendicular to an axis of the protective tube body,

thermo-couples are provided within the branch tubes respectively, and

the branch tubes are interposed between the objects to be processed at different vertical levels.

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

the protective tube body of the second temperature sensor can be rotated about its axis.

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

an annular groove is formed on a circumference of a

proximal end portion of the protective tube body of the second temperature sensor.

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

the interior within the protective tube body and the branch tubes is in a negative pressure, and

the proximal end portion of the protective tube body is air-tightly sealed.

12. A temperature sensor for correcting a temperature, comprising:

a straight, vertically extending protective tube body; and

a plurality of branch tubes being vertically spaced apart from each other, each of the branch tubes extending from the protective tube body in a direction perpendicular to an axis of the protective tube body; wherein

thermo-couples are provided within the branch tubes respectively, and

the branch tubes are interposed between objects to be processed at different vertical levels.