SUBSTRATE PROCESSING APPARATUS, REACTION TUBE, METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE, AND PROGRAM

TECHNICAL FIELD

[0001] The present disclosure relates to a substrate processing apparatus, a reaction tube, a method of manufacturing a semiconductor device, and a recording medium.

BACKGROUND

[0002] In Patent Document 1, there is described a substrate processing apparatus that forms a film on the surface of each of the substrates in a state in which the substrates are held in multiple stages by a substrate holder in a process furnace.

[Prior Art Documents]

[0003] Patent Documents

Patent Document 1: Japanese Patent Application Laid-open No. 2019-165210

[0004] In order to safely load and unload the substrate holder into and from the process furnace and to rotate the substrate holder, it is necessary to form a gap between a top plate of the substrate holder and an inner surface of a reaction tube that constitutes a process furnace for accommodating the substrate holder. Further, a product substrate used as a product has a larger surface area than a monitoring substrate or a dummy substrate not used as a product. Therefore, consumption of a processing gas when processing the product substrate is large.

[0005] Therefore, the uniformity of the formed film may deteriorate by an excess gas generated in the gap between the top plate of the substrate holder and the inner surface of the reaction tube. Such deterioration of the uniformity is called a loading effect.

SUMMARY

[0006] Some embodiments of the present disclosure provide a technique capable of improving the inter-plane/in-plane uniformity of a film formed on a substrate.

[0007] According to embodiments of the present disclosure, there is provided a technique that

The pod transfer device 118 is configured to transfer the pod 110 between the pod stage 114, the pod mounting shelf 105, and the pod opener by the continuous operation of the pod elevator 118a and the pod transfer mechanism 118b. The pod opener is configured to open the lid of the pod 110. The wafer number detector is configured to detect the number of wafers 200 in the pod 110 with the lid opened.

[0024] A wafer transfer machine 125 and a boat 217 as a substrate holder are provided in the housing 111. The wafer transfer machine 125 includes an arm (tweezer) 125c and has a structure capable of being raised or lowered in the vertical direction and rotated in the horizontal direction by a driving means (not shown). The arm 125c is configured to take out, for example, five wafers at the same time. By moving the arm 125c, the wafer 200 is transferred between the pod 110 placed at the position of the pod opener and the boat 217.

[0025] Next, the operation of the substrate processing apparatus 101 according to the present embodiments will be described.

[0026] First, the pod 110 is placed on the pod stage 114 by an in-process transfer device (not shown) such that the wafers 200 take a vertical posture and the wafer loading/unloading port of the pod 110 faces upward. Thereafter, the pod 110 is rotated by 90 degrees in a vertical direction toward the rear side of the housing 111 by the pod stage 114. As a result, the wafers 200 in the pod 110 take a horizontal posture, and the wafer loading/unloading port of the pod 110 faces rearward in the housing 111.

[0027] Next, the pod 110 is automatically transferred to a designated shelf position of the pod mounting shelf 105 by the pod transfer device 118, delivered to the pod mounting shelf 105, and temporarily stored on the pod mounting shelf 105. Then, the pod 110 is delivered from the pod mounting shelf 105 to the pod opener or transferred directly to the pod opener.

[0028] When the pod 110 is transferred to the pod opener, the lid of the pod 110 is opened by the pod opener. Then, the number of wafers in the pod 110 with the lid opened is detected by the wafer number detector. The wafer 200 is picked up from an inside of the pod 110 by the arm 125c of the wafer transfer machine 125 through the wafer loading/unloading port and is charged into the boat 217 by the transfer operation of the wafer transfer machine 125. The wafer

(5) Simulation

[0090] Hereinafter, the present embodiments will be described by comparison with a comparative example.

[0091] Comparison was made between a case (hereinafter referred to as Present Example) where a wafer 200 as a product substrate having an area 200 times larger than that of a bare wafer is subjected to substrate processing by the above-described method of manufacturing a semiconductor device using the process furnace 202 according to the present embodiments as shown in FIG. 2 and a case where a wafer 200 as a product substrate is subjected to substrate processing by the above-described method of manufacturing a semiconductor device using the process furnace according a Comparative Example, which differs only in that it does not have the protrusion 204b or the opening of the top plate 211.

[0092] The process furnace according to the Comparative Example has a flat shape on the inner surface side of the ceiling of the inner tube and is not provided with the protrusion 204b. Further, the top plate of the boat is disk-shaped and no opening is formed in the top plate. Further, a plurality of dummy substrates is stacked on the boat at the upper and lower ends in the arrangement direction of the wafers 200 as product substrates. That is, the cover 400 is not provided at the bottom of the boat.

[0093] FIG. 9A is a diagram showing the distribution of a partial pressure of $SiCl_2$ that is a decomposition product of a Si_2Cl_6 gas in the process furnace according to the Comparative Example at the time of supplying the Si_2Cl_6 gas, and FIG. 9B is a diagram showing the distribution of a partial pressure of $SiCl_2$ as a decomposition product of a Si_2Cl_6 gas in the process furnace 202 according to the Present Example at the time of supplying the Si_2Cl_6 gas.

[0094] FIGS. 9A and 9B show that a Si_2Cl_6 gas is supplied from the left side. As shown in FIG. 9A, in the process furnace according to the Comparative Example, the Si_2Cl_6 gas is supplied to the wafers at a high concentration in the upper part of the process furnace (near the ceiling). On the other hand, as shown in FIG. 9B, in the process furnace 202 according to the present embodiments, the concentration of the Si_2Cl_6 gas in the upper part of the process furnace 202 (near the ceiling) is alleviated as compared with the case where the process furnace according to

the Comparative Example is used. Thus, the difference in the concentration of the Si_2Cl_6 gas between the wafers is alleviated and the distribution of the partial pressure of $SiCl_2$ is the same in the arrangement direction of the wafers.

[0095] FIG. 10A is a diagram showing the wafer inter-plane uniformity that evaluates the average value of the $SiCl_2$ partial pressures on the wafers at the respective slot numbers. FIG. 10B is a diagram showing the wafer in-plane uniformity that compares the numerical values obtained by dividing the difference between the center and the outer periphery of each of the wafers at the respective slot numbers by an average value. As for the slot number, the larger the number, the higher the wafer is arranged in the boat 217.

[0096] As shown in FIG. 10A, when a SiN film is formed on the wafer using the process furnace according to the Comparative Example, the $SiCl_2$ partial pressure is higher on the wafers in the upper and lower stages of the boat than on the wafers in the middle stage. That is, the film thickness of the SiN film formed on the wafer in the upper and lower stages is larger than the film thickness of the SiN film formed on the wafer in the middle stage. Further, the difference between the maximum value and the minimum value of the $SiCl_2$ partial pressure is 0.242.

[0097] On the other hand, when the SiN film is formed on the wafer by using the process furnace 202 according to the Present Example, the $SiCl_2$ partial pressure is lowered in the upper stage of the boat 217 and the variation of the $SiCl_2$ partial pressure is improved, as compared with the case where the process furnace according to the Comparative Example is used. That is, the film thickness of the SiN film formed on the wafer in the upper stage is equal to the film thickness of the SiN film formed on the wafer in the middle stage. Further, the difference between the maximum value and the minimum value of the $SiCl_2$ partial pressure is 0.131 which is half of 0.242 which is the difference between the maximum value and the minimum value of the $SiCl_2$ partial pressure in the Comparative Example. That is, the inter-plane uniformity (wafer to wafer uniformity) is improved as compared with the case where the process furnace according to the Comparative Example is used.

[0098] Further, as shown in FIG. 10B, when a SiN film is formed on the wafer by using the process furnace according to the Comparative Example, the in-plane uniformity (within wafer

WHAT IS CLAIMED IS:

1. A substrate processing apparatus, comprising:

a substrate holder configured to arrange and hold substrates; and

a reaction tube in which the substrate holder is accommodated,

wherein the substrate holder includes:

a plurality of pillars installed around the arranged substrates and extending in a direction substantially perpendicular to the substrates;

a top plate configured to fix one ends of the plurality of pillars to each other and having an opening at a center of the top plate; and

a bottom plate configured to fix other ends of the plurality of pillars to each other,

wherein the reaction tube includes a protrusion protruding inward in a shape corresponding to a shape of the opening of the top plate and having a flat leading end, and

wherein the protrusion is installed to be inserted into the opening of the top plate in a state where the substrate holder is accommodated in the reaction tube, and is configured to be closer to a substrate arranged closest to the top plate of the substrate holder than the top plate.

2. The substrate processing apparatus of Claim 1, wherein a height of the protrusion is set such that a distance between the protrusion and the substrate arranged closest to the top plate on the substrate holder is substantially equal to a distance between the substrates adjacent to each other on the substrate holder.

3. The substrate processing apparatus of Claim 1, wherein the reaction tube includes:

an inner tube configured to accommodate the substrate holder; and

an outer tube having a pressure-resistant structure and configured to accommodate the inner tube,

wherein the inner tube includes a ceiling terminating an upper portion of the inner tube,

and

wherein the protrusion is installed at the ceiling.

4. The substrate processing apparatus of Claim 3, further comprising:

a nozzle extending parallel to an arrangement direction of the substrates and configured to supply a gas to each of the arranged substrates,

wherein the inner tube further includes a bulging portion formed by bulging outward on a side surface of the inner tube and configured to accommodate the nozzle in the bulging portion.

5. The substrate processing apparatus of Claim 1, further comprising:

a rotary shaft configured to rotatably support the substrate holder,

wherein the opening and the protrusion are formed in a circular shape concentric with the rotary shaft.

6. The substrate processing apparatus of Claim 1, further comprising:

a cover configured to surround a plurality of arrangement positions including an arrangement position closest to the bottom plate among arrangement positions of the substrates on the substrate holder, from an upper surface and a side surface of the plurality of arrangement positions,

wherein the substrate holder is configured to hold a plurality of product substrates or monitoring substrates at a plurality of arrangement positions between the cover and the top plate without holding the plurality of product substrates and the monitoring substrates at the plurality of arrangement positions surrounded by the cover.

7. The substrate processing apparatus of Claim 4, further comprising:

a cover configured to surround a plurality of arrangement positions including an arrangement position closest to the bottom plate among arrangement positions of the substrates on the substrate holder, from an upper surface and a side surface of the plurality of arrangement

positions,

wherein the nozzle includes a plurality of gas supply ports at positions corresponding to a plurality of product substrates or monitoring substrates held at a plurality of arrangement positions between the cover and the top plate without having gas supply ports at positions corresponding to the plurality of arrangement positions surrounded by the cover.

8. The substrate processing apparatus of Claim 3, wherein an entire inner surface of the ceiling of the inner tube is formed along a shape of the top plate of the substrate holder.

9. The substrate processing apparatus of Claim 1, further comprising:

a lid configured to close an opening through which the substrate holder is loaded into and unloaded from a process vessel constituted by the reaction tube;

a rotation mechanism installed on the lid to hold the substrate holder in the reaction tube; and

a sealing member configured to seal a gap between the reaction tube and the lid without allowing the reaction tube to directly contact the lid,

wherein a height of the protrusion is set such that, when the sealing member has a predetermined crushing amount capable of sealing, a distance between the protrusion and the substrate arranged closest to the top plate is substantially equal to a distance between the substrates adjacent to each other in the substrate holder.

10. The substrate processing apparatus of Claim 1, further comprising:

a lid configured to close an opening through which the substrate holder is loaded into and unloaded from a process vessel constituted by the reaction tube;

a rotation mechanism provided on the lid to hold the substrate holder in the reaction tube; and

a sealing member configured to seal a gap between the reaction tube and the lid without allowing the reaction tube to directly contact the lid,

wherein a height of the protrusion is set such that, when the sealing member has a predetermined crushing amount capable of sealing, a distance between the protrusion and the substrate arranged closest to the top plate is sufficiently smaller than a distance between the substrates adjacent to each other in the substrate holder and larger than a variation of the predetermined crushing amount.

11. The substrate processing apparatus of Claim 6, wherein the substrate holder is configured to hold the plurality of product substrates or the monitoring substrates at a plurality of arrangement positions between the cover and the top plate excluding the arrangement position closest to the top plate.

12. A reaction tube in which a substrate holder is accommodated, comprising:

a protrusion that protrudes inward in a shape corresponding to a shape of an opening of a top plate of the substrate holder configured to arrange and hold substrates, and has a flat leading end,

wherein the protrusion is installed to be inserted into the opening of the top plate in a state where the substrate holder is accommodated in the reaction tube, and protrudes inward such that the protrusion is closer to a substrate arranged closest to the top plate of the substrate holder than the top plate.

13. A method of manufacturing a semiconductor device, comprising:

accommodating a substrate holder, which is configured to arrange and hold substrates and includes a plurality of pillars installed around the arranged substrates and extending in a direction substantially perpendicular to the substrates, a top plate configured to fix one ends of the plurality of pillars to each other and having an opening at a center of the top plate, and a bottom plate configured to fix other ends of the plurality of pillars to each other, into a reaction tube which includes a protrusion protruding inward in a shape corresponding to a shape of the opening of the top plate and having a flat leading end; and

processing the substrates in the reaction tube,

wherein in the act of accommodating the substrate holder, the protrusion is inserted into the opening of the top plate and is brought closer to a substrate arranged closest to the top plate of the substrate holder than the top plate.

14. A program that causes, by a computer, a substrate processing apparatus to perform a process comprising:

accommodating a substrate holder, which is configured to arrange and hold substrates and includes a plurality of pillars installed around the arranged substrates and extending in a direction substantially perpendicular to the substrates, a top plate configured to fix one ends of the plurality of pillars to each other and having an opening at a center of the top plate, and a bottom plate configured to fix other ends of the plurality of pillars to each other, into a reaction tube which includes a protrusion protruding inward in a shape corresponding to a shape of the opening of the top plate and having a flat leading end; and

processing the substrates in the reaction tube,

wherein in the act of accommodating the substrate holder, the protrusion is inserted into the opening of the top plate and is brought closer to a substrate arranged closest to the top plate of the substrate holder than the top plate.