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Apparatus for processing a substrate and method of operating the same

Abstract

An apparatus for processing a substrate includes a reaction tube, a side cover, a heater, a first gas supplier, a second gas supplier and a controller. The reaction tube is configured to receive a substrate boat in which a plurality of the substrate is received to process the substrate. The side cover is configured to receive the reaction tube. The heater lines the interior of the side cover. The first gas supplier is provided to an upper portion of the side cover to supply a cooling gas at a first supplying rate to a space between the side cover and the reaction tube. The second gas supplier is provided to a lower portion of the side cover to supply the cooling gas at a second supplying rate different from the first supplying rate to the space between the side cover and the reaction tube. The controller controls the reaction tube.

Inventors: Jung; Min Jin (Hwaseong-si, KR), Kim; Tae Hwan (Yongin-si, KR), Kang; Min Woong (Hwaseong-si, KR), Yoo; Hyun Jun (Seoul, KR), Kang; Sung Ho (Yongin-si, KR), Park; Song Hwan (Yongin-si, KR), Kim; Bo Sun (Yongin-si, KR), Lee; Hong Won (Yongin-si, KR), Cho; Joo Hyun (Yongin-si, KR), Jin; Yong Tak (Yongin-si, KR)

Applicant: SK hynix Inc. (Icheon-si, KR); EUGENE TECHNOLOGY CO., LTD. (Yongin-si, KR)

Family ID: 1000008764770

Assignee: SK hynix Inc. (Icheon-si, KR); EUGENE TECHNOLOGY CO., LTD. (Yongin-si, KR)

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Primary Examiner: Bennett; Charlee J. C.

Attorney, Agent or Firm: WILLIAM PARK & ASSOCIATES LTD.

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation-in-part of U.S. patent application Ser. No. 16/700,921, filed on Dec. 2, 2019, which claims priority under 35 U.S.C. § 119(a) to Korean Application No. 10-2019-0071561, filed on Jun. 17, 2019, in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein by reference.

BACKGROUND

1. Technical Field

(1) Various embodiments may generally relate to an apparatus and a method of processing a substrate, more particularly, to an apparatus and a method of processing a substrate that may be capable of controlling a cooling speed and temperature uniformity in a reaction tube.

2. Related Art

(2) Semiconductor fabrication processes may include a process of processing a substrate to form a layer on the substrate through a chemical vapor deposition (CVD) process. The substrate processing process may include loading a substrate boat with a plurality of the substrates into a reaction tube, and supplying a reaction gas into the reaction tube in a vacuum.

(3) The temperature of the substrate may increase during the substrate processing process. Thus, after the substrate processing process, it may be required to cool the substrate boat in order to transfer the substrate. An atmospheric pressure may be applied to the reaction tube. External air or nitrogen gas may also be supplied to the reaction tube to cool the reaction tube. An unloading temperature of the substrate boat may be controlled. The substrate boat may then be unloaded from the reaction tube.

(4) When the reaction tube is naturally cooled, a cooling time may be so long so that the productivity level may decline. In contrast, when the reaction tube is rapidly cooled, a crack may be generated at byproducts on an inner wall of the reaction tube, generated in the substrate processing process. Particles may be generated from the crack of the byproducts.

(5) Therefore, a technology for cooling the reaction tube, while preventing productivity loss from natural cooling and minimizing stresses applied to the byproducts caused by a forced cooling, is being pursued.

SUMMARY

(6) In example embodiments of the present disclosure, an apparatus for processing a substrate may include a reaction tube, a side cover, a heater, a first gas supplier, a second gas supplier and a controller. The reaction tube may be configured to receive a substrate boat in which a plurality of the substrate may be received to process the substrate. The heater may line the interior of the side cover. The side cover may be configured to receive the reaction tube. The first gas supplier may be

provided to an upper portion of the side cover to supply a cooling gas at a first supplying rate to a space between the side cover and the reaction tube. The second gas supplier may be provided to a lower portion of the side cover to supply the cooling gas at a second supplying rate different from the first supplying rate to the space between the side cover and the reaction tube. The controller may control the reaction tube.

(7) In example embodiments of the present disclosure, based on a method of processing a substrate, substrates in a substrate boat may be processed in a reaction tube. A cooling gas may be supplied to a space between the reaction tube and a side cover, which may be configured to receive the reaction tube, to cool the reaction tube to no more than a predetermined temperature. The substrate boat may then be unloaded from the reaction tube. In example embodiments, the cooling of the reaction tube may include supplying the cooling gas at a first supplying rate to an upper region of the space, supplying the cooling gas at a second supplying rate, different from the first supplying rate to a lower region of the space. The cooling gas may then be exhausted from the space.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The above and another aspect, features and advantages of the subject matter of the present disclosure will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

(2) FIGS. 1A to 1C are exploded perspective views, illustrating an apparatus for processing a substrate, in accordance with example embodiments;

(3) FIG. 2A is a longitudinal cross-sectional view, illustrating an apparatus for processing a substrate, in accordance with example embodiments;

(4) FIG. 2B is a side view showing gas transmission holes of a side cover, in accordance with example embodiments;

(5) FIG. 2C is a cross-sectional view showing a unit heater, in accordance with example embodiments;

(6) FIG. 3A is a plane view showing a unit heater in accordance with example embodiments;

(7) FIG. 3B is a perspective views showing the unit heater in accordance with example embodiments;

(8) FIG. 3C is a perspective view showing stacked unit heaters in accordance with example embodiments;

(9) FIG. 4A is a flow chart, illustrating a method of processing a substrate, in accordance with example embodiments;

(10) FIGS. 4B to 4D are flow charts, illustrating a process for cooling a reaction tube, in accordance with example embodiments;

(11) FIG. 5 is a block diagram, illustrating a controller, in accordance with example embodiments; and

(12) FIG. 6 is a cross-sectional view, illustrating an apparatus for processing a substrate, in accordance with example embodiments.

DETAILED DESCRIPTION

(13) Various embodiments of the present invention will be described in greater detail with reference to the accompanying drawings. The drawings are schematic illustrations of various embodiments (and intermediate structures). As such, variations from the configurations and shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, the described embodiments should not be construed as being limited to the particular configurations and shapes illustrated herein but may include deviations in configurations and shapes which do not depart from the spirit and scope of the present invention as defined in the

appended claims.

(14) The present invention is described herein with reference to cross-section and/or plan illustrations of idealized embodiments of the present invention. However, embodiments of the present invention should not be construed as limiting the inventive concept. Although a few embodiments of the present invention will be shown and described, it will be appreciated by those of ordinary skill in the art that changes may be made in these embodiments without departing from the principles and spirit of the present invention.

(15) FIGS. 1A to 1C are exploded perspective views, illustrating an apparatus for processing a substrate, in accordance with example embodiments. FIG. 2A is a longitudinal cross-sectional view, illustrating an apparatus for processing a substrate, in accordance with example embodiments. FIG. 2B is a side view showing gas transmission holes of a side cover, in accordance with example embodiments. FIG. 2C is a cross-sectional view showing a unit heater, in accordance with example embodiments. FIG. 3A is a plane view showing a unit heater in accordance with example embodiments. FIG. 3B is a perspective view showing the unit heater in accordance with example embodiments. FIG. 3C is a perspective view showing stacked unit heaters in accordance with example embodiments.

(16) Referring to FIG. 1A to FIG. 3C, an apparatus **100** for processing a substrate, in accordance with example embodiments, may include a substrate boat **110**, a reaction tube **120**, a side cover **130**, a heater **140**, a lid **150**, a cooling gas supplier GS, an exhauster **180** and a controller **200**.

(17) The substrate boat **110** may process a plurality of substrates **10** at the same time. For example, the substrate boat **110** may extend along a first direction D1. Further, the plurality of substrates **10**, such as a plurality of wafers, may be sequentially received along the first direction D1 in the substrate boat **110**. The substrate boat **110** may have a plurality of processing spaces A1~An in which the substrates **10** may be individually processed.

(18) The reaction tube **120** may have an internal space IS. The substrate boat **110** may be inserted in the internal space IS of the reaction tube **120** during the substrate-processing step. The reaction tube **120** may include a single tube or a plurality of tubes. For example, the reaction tube **120** may include an inner tube **120a** and an outer tube **120b**.

(19) The side cover **130** may be arranged to surround the reaction tube **120**. The side cover **130** may have a cylindrical shape having an opened upper surface and an opened lower surface. The side cover **130** may be spaced apart from the outer surface of the reaction tube **120** by a setting distance. The side cover **130** may include a metal, such as a stainless metal. The side cover **130** may include a plurality of gas transmission holes **131**. For example, the plurality of gas transmission holes **131** may be arranged along the first direction D1 with a uniform gap. The gas transmission holes **131** may be arranged at a selected portion of the side cover **130**.

(20) The heater **140** may apply heat to the reaction tube **120**. The heater **140** may be arranged between the reaction tube **120** and the side cover **130**. For example, the heater **140** may extend in the first direction D1. For example, the heater **140** may also include a substantially cylindrical structure having a diameter smaller than a diameter of the side cover **130** and larger than the diameter of the reaction tube **120**.

(21) For example, the heater **140** may include a plurality of first holes **165a** extending a second direction D2 and a third direction D3 for forming a horizontal plane. The heater **140** extending in the first direction D1 may be divided into a plurality of unit heaters **145** by the plurality of first holes **165a**.

(22) In an example embodiment, referring to FIG. 2C, each of the unit heaters **145** may include an adiabatic block **141** and a coil **142**. For example, the adiabatic block **141** may include an annular shape. The adiabatic block **141** may include at least one of silica and alumina as a main material. For example, the adiabatic block **141** may have a thickness T1 of about 30 mm to about 40 mm. The coil **142** may be arranged on an inner surface of the adiabatic block **141** in a linear shape such as a spiral shape, an oblique shape, etc.

- (23) Each of the unit heaters **145** may further include an adhesion pattern **143** for bonding an outer surface of the adiabatic block **141** and an inner surface of the side cover **130**. The adhesion pattern **143** may have an annular shape. The adhesion pattern **143** may include a thickness T2 that is shallower than the thickness T1 of the adiabatic block **141**. For example, the thickness T2 of the adhesion pattern **143** may be about 15 mm to about 20 mm and a width of the adhesion pattern **143** may be about 30 mm to about 50 mm, but it is not limited here. For example, the adhesion pattern **143** may be positioned between the adjacent first holes **165a**. As described above, the adhesion patterns **143** of the unit heater **145** may attach the adiabatic block **141** to the inner surface of the side cover **130**, respectively. Since the thickness T2 of the adhesion pattern **143** is shallower than the thickness T1 of the adiabatic block **141**, inner passageways **135** may be defined between the adhesion patterns **143** of the adjacent unit heaters **145**.
- (24) Each of the unit heaters **145** may further include a plurality of second holes **165b**, as shown in FIG. 3A to FIG. 3C. The plurality of second holes **165b** may be formed in the adiabatic block **141** of each unit heater **145**. That is, the adiabatic block **141** of each unit heater **145** may be divided into a plurality of adiabatic regions **141a** by the plurality of second holes **165b**. For example, the plurality of second holes **165b** may be radially formed in the adiabatic block **141** of each unit heater **145**.
- (25) In example embodiments, the first hole **165a** may be positioned between adjacent adiabatic blocks **141**, the second hole **165b** may be positioned between adjacent adiabatic regions **141a**, and the inner passageway **135** may be positioned between adjacent adhesion patterns **143**.
- (26) The plurality of unit heaters **145** may provide different temperatures depending on a height of the reaction tube **120**, respectively.
- (27) As described above, the internal space SP of the apparatus **100** may be vertically divided into a plurality of sub-spaces A1~An along the first direction D1. For example, each of the unit heaters **145** may be located for each of the sub spaces A1~An. Temperatures of the sub spaces A1~An may be individually controlled by the unit heaters **145**, respectively.
- (28) The lid **150** may be arranged on the upper end of the side cover **130**. The lid **150** may be configured to seal the opened upper surface of the side cover **130**. The lid **150** may include a metal material, such as a stainless metal.
- (29) The cooling gas supplier GS may supply the cooling gas to the internal space SP of the apparatus **100**. The cooling gas supplier GS may include a first gas supplier **160** and a second gas supplier **170**. The first gas supplier **160** may provide a cooling gas to an upper portion UP of the apparatus **100**. For example, the cooling gas may include at least one external air and nitrogen gas. The first gas supplier **160** may be positioned at an upper region of an outer surface of the side cover **130**.
- (30) The first gas supplier **160** may include a first duct **161** and at least one first gas line **162**. The first duct **161** may be installed outside of the side cover **130**. The first duct **161** may be positioned to cover the gas transmission holes **131H** arranged in the side cover **130** defined by the upper portion UP. The first duct **161** may be arranged to have a setting distance from the outer surface of the side cover **130** while covering the gas transmission holes **131H** arranged in the side cover **130**. Thus, a first external cooling space AP1 may be defined between the first duct **161** and the outer surface of the side cover **130**.
- (31) The first gas supplier **160** may further include a first inlet **163** and at least one first opening/closing valve **167**. The first inlet **163** may insert and fix the first gas line **162** to the first duct **161**. The first opening/closing valve **167** may be installed in the first gas line **162** and may control a supplying of the cooling gas.
- (32) The second gas supplier **170** may provide the cooling gas to a lower portion LP of the apparatus **100**. The second gas supplier **170** may be positioned at a lower region of the outer surface of the side cover **130**.
- (33) The second gas supplier **170** may include a second duct **171** and at least one second gas line

172. The second duct **171** may be installed outside of the side cover **130** under the first duct **161**. More detailed, the second duct **171** may be positioned to cover the gas transmission holes **131L** arranged in the side cover **130** defined by the lower portion LP. The second duct **171** may be arranged to have the setting distance from the outer surface of the side cover **130** while covering the gas transmission holes **131L** arranged in the side cover **130**. Thus, a second external cooling space AP2 may be defined between the second duct **171** and the outer surface of the side cover **130**.

(34) At least one of the first gas supplier **160** and the second gas supplier **170** may include at least one partition **165c**. The partition **165c** may be positioned between the one of the first and second ducts **161** and **171** and the outer surface of the side cover **130** to be parallel to the horizontal direction. For example, the partition **165c** may be arranged at an interface between the upper portion UP and the lower portion LP. The first external cooling space AP1 and the second external cooling space AP2 may be divided by the partition **165c**.

(35) In example embodiments, the first duct **161** may have a length that is longer than that of the second duct **171**. Thus, the first duct **161** may cover a greater number of the gas transmission holes **131H** than the second duct **171**.

(36) The second gas supplier **170** may further include a second inlet **173** and at least one first opening/closing valve **177**. The second inlet **173** may insert and fix the second gas line **172** to the second duct **171**. The second opening/closing valve **177** may be installed in the second gas line **172** and may control a supplying of the cooling gas.

(37) In example embodiments, the first gas line **162** may have a larger diameter than a diameter of the second gas line **172**, to supply more cooling gas to the upper portion UP, as shown in FIG. **18**.

(38) In example embodiments, a diameter of the first gas line **162** may be the same as a diameter of the second gas line **172**. When the first gas line **162** and the second gas line **172** has the same diameter, the first gas supplier **160** may include a greater number of first gas lines **162** than the number of second gas lines **172**, to supply more cooling gas to the upper portion UP, as shown in FIG. **1C**.

(39) The exhauster **180** may be installed on the side cover **130**. For example, the exhauster **180** may be connected with the lid **150** to exhaust the cooling gas in the side cover **130**.

(40) Air inside the apparatus **100**, especially, the side cover **130**, may be heated by the substrate-processing step. The heated air (hereinafter, hot air) is lighter than the cooling gas, it is mainly distributed at the upper portion UP of the apparatus **100** by convection. For this reason, the temperature of the upper portion UP may be relatively higher than the temperature of the lower portion LP. Thus, to solve a non-uniformity of the temperature of the apparatus **100**, the cooling gas provided by the first gas supplier **160** is greater than the cooling gas provided by the second gas supplier **170**. Further, a concentration of the hot air in the upper portion UP of the apparatus **100** becomes more severe, because the cooling gas provided from the first and second gas supplier **160** and **170** may be heated during the substrate-processing step. The concentration of the hot air may change the process conditions of the substrates **10** in the reaction tube **120**. Accordingly, a process deviation may occur depending on a position of the substrate **10** in the reaction tube **120**.

(41) In example embodiments, the exhauster **180** may be disposed in the upper portion UP where a relatively large amount of the hot air is distributed compared to the lower portion LP, so that the hot air may be discharged faster than the lower portion LP.

(42) In example embodiments, the exhauster **180** may include a first exhaust line **181**, an exhausting gas processing unit **182**, a second exhaust line **183**, an exhausting valve **185**, and an exhaust measurement member **187**.

(43) The first exhaust line **181** may be inserted into the lid **150**. One end of the first exhaust line **181** may be connected to the internal space SP through the lid **150**.

(44) The exhausting gas processing unit **182** may be connected between the first exhaust line **181** and the second exhaust line **183**. For example, the exhausting gas processing unit **182** may remove by-product and ignition material in the exhaust gas.

- (45) The second exhaust line **183** may be connected between the exhausting gas processing unit **182** and a pump (or blower, not shown).
- (46) The exhausting valve **185** may be installed in the second exhaust line **183**. For example, the exhausting valve **185** may be closed during the exhausting operation of the apparatus **100**.
- (47) The exhaust measurement member **187** may be installed in at least one of the first exhaust line **181**, the exhausting gas processing unit **182** and the second exhaust line **183**. The exhaust measurement member **187** may measure an exhaust pressure and/or the exhaust speed of the exhauster **180**. The exhaust pressure and/or the exhaust speed measured by the exhaust measurement member **187** may be transmitted to the controller **200**.
- (48) In example embodiment, an exhausting amount of the exhauster **180** may be greater than a supplying amount of the first gas supplier **160**. Further, the exhausting amount of the exhauster **180** may be greater than a supplying amount of the second gas supplier **170**. In addition, the exhausting amount of the exhauster **180** may be greater than the supplying amounts of the first and second gas suppliers **160** and **170**.
- (49) In example embodiment, the exhausting amount of the exhauster **180** may be adjusted by a diameter of the first exhaust line **181**. For example, the diameter of the first exhaust line **181** may be greater than the diameter of the first gas line **162**. Further, the diameter of the first exhaust line **181** may be greater than the diameter of the second gas line **172**. For example, the exhausting amount of the exhauster **180** may be adjusted by a capacity of the pump (or the blower).
- (50) In example embodiment, the cooling gas through the first gas line **162** of the first gas suppliers **160** may be transmitted to the first external cooling space AP1 defined by the first duct **161** and the partition **165c**. The cooling gas in the first external cooling space AP1 may be evenly diffused along the outer surface of the side cover **130** to cool the side cover **130**. The cooling gas in the first external cooling space AP1 may be transmitted to the inner passageways **135** in the side cover **130** through the gas transmission holes **131H**. The cooling gas in the inner passageways **135** may evenly cool the inner surface of the side cover **130**, the adhesion patterns **143** and the is outer surface of the adiabatic block **141** defining the inner passageway **135**. And then, the cooling gas in the inner passageways **135** may be transmitted to the internal space SP through the plurality of first and second holes **165a** and **165b**. For example, the cooling gas flowing through the first holes **165a** may cool the unit heaters **145** adjacent to the corresponding first hole **165a**. Since the plurality of second holes **165b** are radially arranged in the adiabatic block **141** of the unit heater **145**, the plurality of adiabatic regions **141a** constituting the unit heater **145** may be rapidly and evenly cool by the cooling gas flowing through the plurality of second holes **165b**.
- (51) A cooling operation of the second gas supplier **170** may also be substantially the same as the above cooling operation of the first gas supplier **160**.
- (52) The controller **200** may be configured to control the cooling rate of the apparatus **100**, with the reaction tube **120**. FIG. 5 is a block diagram illustrating a controller in accordance with example embodiments.
- (53) Referring to FIG. 5, the controller **200** may control the cooling rate of the reaction tube **120**. For example, the controller **200** may individually control the cooling rates of the vertically arranged sub-spaces A1~An in the apparatus **100**. The controller **200** may include a heater control member **210**, a cooling gas control member **220** and an exhaust control member **230**. Operations of the heater control member **210**, the cooling gas control member **220** and the exhaust control member **230** may be illustrated later.
- (54) The unit heaters **145** in each sub-spaces A1~An may be individually controlled by the heat control member **210**.
- (55) The heater control member **210** may drive the unit heater **145** in the region having a relatively low temperature in accordance with a temperature distribution of the regions A1~An to compensate for the low temperature of the region. As a result, the temperature uniformity in the reaction tube **120** may be maintained.

(56) FIG. 6 is a cross-sectional view, illustrating an apparatus for processing a substrate, in accordance with example embodiments.

(57) Referring to FIG. 6, the apparatus **100**, for processing the substrate, may further include a temperature sensor **190**.

(58) The temperature sensor **190** may measure temperatures of the regions **A1~An** in the reaction tube **120**. The measured temperatures, by the temperature sensor **190**, may be provided to the controller **200**. The controller **200** may recognize the temperature distribution based on the regions **A1~An**.

(59) The temperature sensor **190** may include a first temperature detection member **191** and a second temperature detection member **192**.

(60) The first temperature detection member **191** may be arranged in the reaction tube **120** to measure the temperatures of the regions **A1~An**. The first temperature detection member **191**, in the reaction tube **120**, may measure the temperature in the reaction tube **120** in a vacuum state to identify whether the reaction tube **120** can be normally cooled or not. The first temperature detection member **191** may be positioned adjacent to the substrate **10** in the reaction tube **120** to measure the temperature in the reaction tube **120**. The measured temperature, by the first temperature detection member **191**, may correspond to a peripheral temperature of the substrate **10**. Thus, a temperature of the substrate **10** may be estimated from the peripheral temperature of the substrate **10**.

(61) The first temperature detection member **191** may include a profile thermocouple. The profile thermocouple may be installed between the inner tube **120a** and the outer tube **120b** of the reaction tube **120**. Alternatively, the first temperature detection member **191** may be arranged in the reaction tube **120**, for example, the inner tube **120a** to measure an actual temperature in the reaction tube **120**.

(62) The second temperature detection member **192a-192n** may be arranged between the reaction tube **120** and the heater **140**. The second temperature detection member **192a-192n** may measure the temperatures of the regions **A1~An**. For example, second temperature detection member **192a-192n** may be connected to the heater **140** to measure a temperature of each of the heating members **145**. The second temperature detection member **192a-192n** may include a spike thermocouple. The second temperature detection member **192a-192n** may be in direct contact with the heater **140** or may be arranged between the heater **140** and the reaction tube **120** to measure the temperature or the atmospheric temperature outside of the reaction tube **120**, surrounding the heater **140**.

(63) The temperatures between the heater **140** and the reaction tube **120**, measured by the second temperature detection member **192a-192n**, may be provided to the controller **200**. The controller **200** may identify whether the regions **A1~An** can be normally cooled or not, based on the provided temperatures.

(64) For example, when a specific region of the regions **A1~An** is not be uniformly cooled, the controller **200** may decrease a heating temperature of the unit heater **145** in the specific region, having a relatively high temperature. In contrast, when a specific region of the regions **A1~An** is cooled relatively rapidly, the controller **200** may increase a heating temperature of the unit heater **145**, in the specific region, having a relatively low temperature.

(65) The temperature controls of the heating members **145** may be performed by the heater control member **210** of the controller **200**. The heater control member **210** may control the heating members **145** to supply thermal energy to a region among the regions **A1~An** having a relatively low temperature, based on the temperatures of the regions **A1~An** measured by the temperature detection members **191** and **192a-192n**. As mentioned above, because the hot air may be positioned in the upper region of the reaction tube **120** and the cold air may be positioned in the lower region of the reaction tube **120** due to convection, the temperature deviation between the upper region and the lower region in the reaction tube **120** may be generated.

(66) In order to reduce the temperature deviation, the heater control member **210** may

independently control the heating members **145** in a region among the regions **A1~An**, having a non-uniform temperature distribution, based on the temperatures of the regions **A1~An**, measured by the temperature detection members **191** and **192a-192n**.

(67) The second gas supplier **170** may be positioned at a lower portion of the side cover **130**. The second gas supplier **170** may include a second duct **171**, connected to the gas supply holes **165** located, outside the lower region of the reaction tube **120**.

(68) The first duct **161** and the second duct **171** may supply and distribute the cooling gas. For example, the first duct **161** may extend in a downward direction from an outer surface of the upper portion of the side cover **130**. The second duct **171** may be upwardly extended from an outer surface of the lower region of the side cover **130**. The first duct **161** may be connected to the second duct **171**. An external cooling space may be formed between the first gas supplier **160**, the second gas supplier **170**, the first duct **161**, the second duct **171** and the side surface of the side cover **130**.

(69) The plurality of first holes **165a** may be provided to the regions **A1~An**, respectively. That is, the gas plurality of first holes **165a** may be positioned in each of the regions **A1~An**.

(70) FIG. 3A is a lateral cross-sectional view, illustrating an apparatus for processing a substrate, in accordance with example embodiments, and FIGS. 3B and 3C are perspective views illustrating a heating member in accordance with example embodiments.

(71) Referring to FIG. 3C, the unit heater **145** may include the single adiabatic block **141** or the stacked adiabatic blocks **141**. The first holes **165a** may be provided to each of the adiabatic members **141**. The unit heater **145** may include the vertically arranged first holes **165**.

(72) In example embodiments, in order to provide the cooling gas with a spiral flow along a peripheral direction of the space, between the side cover **130** and the reaction tube **120**, the second holes **165b** may be inclined to a central direction of the adiabatic block **141** at an angle of about 35° from a planar view.

(73) In example embodiments, before installing the side cover **130**, an inner surface or an outer surface of the adiabatic block **141** may be drilled to form the second hole **165**.

(74) The inner passageway **135** may have a width **w1**, greater than a width of the first hole **165a**. The inner passageway **135** may be connected to the first hole **165a**. The inner passageway **135** may be connected to the first duct **161** and/or the second duct **171**.

(75) For example, a plurality of the inner passageways **135** may be vertically arranged between the adiabatic block **141** of the heater **140** and the side cover **130**.

(76) When the cooling gas is injected, from the annular inner passageway **135**, toward the central direction of the adiabatic block **141**, the cooling gas may be injected to the space between the side cover **130** and the reaction tube **120**, through the gas supply hole **165** of the adiabatic block **141**. During the injection of the cooling gas, the spiral flow may be generated in the space between the side cover **130** and the reaction tube **120** along the peripheral direction. The inner passageway **135** may be formed by attaching a band-shaped or an annular adhesion pattern **143** on an outer surface of the adiabatic block **141** or by forming an annular shape on the outer surface of the adiabatic block **141**. The annular inner passageway **135** may be provided to the peripheral of the reaction tube **120** in a tubular shape.

(77) A plurality of connection holes **131** may be formed at the side cover **130**. The connection holes **131** may be spaced apart from each other by a uniform gap. The connection holes **131** may be positioned in a space, defined by the first duct **161** and the second duct **171**. Thus, the external cooling space, the inner passageway **135**, and the gas supply holes **165** may be connected with each other through the connection holes **131**. Each of the gas supply holes **165** may be connected with either the first gas supplier **160**, through the inner passageway **135**, the connection hole **131** and the first duct **161**, or the second gas supplier **170**, through the inner passageway **135**, the connection hole **131** and the second duct **171**.

(78) A blower may be provided to inlets **163** and **171a** of the first and second ducts **161** and **171**

through an opening/closing valve **167**. The blower may draw the external air as the cooling gas.

(79) The cooling gas, introduced into the external cooling space, may be thermally exchanged with the external air so that the cooling gas may be rapidly heated.

(80) The lower region of the space, between the side cover **130** and the reaction tube **120**, where the cold air may be positioned, may have a volume larger than the upper region space between the side cover **130** and the reaction tube **120**, where the hot air may be positioned. Thus, a relatively rapid cooling region has a volume of no more than about 50%, for example, about 10% to about 40% of the volume of the space, between the side cover **130** and the reaction tube **120**. Therefore, in order to cool the relatively rapid cooling region, it might not be required to connect the second duct **171** of the second gas supplier **170**, which may supply the cooling gas having the relatively small amount, with a relatively great amount of the gas supply holes **165**. That is, the second duct **171** may be connected to only the gas supply hole **165** provided to the space or the region having the relatively small volume where the cold air may be positioned. In contrast, the first duct **161** of the first gas supplier **160** may be connected to the relatively great amount of the gas supply holes **165** having the relatively large volume where the hot air may be positioned. As a result, the relatively great amount of the cooling gas may be supplied to the upper region where the hot air may be positioned to effectively cool the upper region.

(81) The first duct **161** and the second duct **171** may be integrally formed with each other. Numbers of the gas supply holes **165** connected with the first duct **161** and the second duct **171** may be determined in accordance with positions of the partition **165c**. For example, when the regions **A1~An** or the internal passageway is divided into seven regions or seven passageways, the first duct **161** may be connected to the five upper passageways **135** and the second duct **171** may be connected to the two lower passageways **135**. Alternatively, a space divided by the first duct **161** and the partition **165c** may have a volume of about 60% to about 90% of the volume of the total space. A space divided by the second duct **171** and the partition **165c** may have a volume of about 10% to about 40% of the volume of the total space.

(82) The apparatus **100** may further include an exhaust measurement member **187**.

(83) The controller **200** may determine whether the measurement results of the exhaust control member **230**, i.e., the exhaust pressure and/or the exhaust speed of the radiant exhauster **180** may be beyond a predetermined set value or not. When the measurement result is beyond the set value, the exhaust control member **230** may output a control signal to decrease the exhaust pressure and/or the exhaust speed of the radiant exhauster **180** to no more than the set value.

(84) The word “predetermined” as used herein with respect to a parameter, such as a predetermined set value, means that a value for the parameter is determined prior to the parameter being used in a process or algorithm. For some embodiments, the value for the parameter is determined before the process or algorithm begins. In other embodiments, the value for the parameter is determined during the process or algorithm but before the parameter is used in the process or algorithm.

(85) When the exhaust pressure and/or the exhaust speed of the radiant exhauster **180** is beyond the set value, stresses, applied to the byproducts on the inner surface of the reaction tube **120**, may be increased to generate a crack in the byproducts. Thus, particles may be generated from the crack in the reaction tube **120**. In order to prevent the generation of the particles, the exhaust pressure and/or the exhaust speed of the radiant exhauster **180** may be monitored and controlled through the exhaust measurement member **187** to prevent the crack and the lamination of the byproducts in the reaction tube **120** and to improve the cooling speed compared to the natural cooling speed.

(86) FIG. 4A is a flow chart, illustrating a method of processing a substrate, in accordance with example embodiments.

(87) Referring to FIG. 4A, in step **S100**, the substrates stacked in the substrate boat may be processed in the reaction tube. In step **S200**, the cooling gas may be supplied to the space between the side cover and the reaction tube to cool the reaction tube to no more than the predetermined set temperature. In step **S300**, the substrate boat may be unloaded from the reaction tube having the

temperature of no more than the set temperature.

(88) Particularly, in step **S100**, the substrates in the substrate boat may be processed in the reaction tube. The substrate-processing step may include a deposition process for forming a layer on the substrate. Because the temperature of the substrate may be increased during the deposition process, it may be required to cool the substrate boat in order to transport the substrate after the deposition process.

(89) In step **S200**, the cooling gas may be supplied to the space between the side cover and the reaction tube to cool the reaction tube to no more than the predetermined set temperature. In order to cool the substrate boat, atmospheric pressure may be applied to the reaction tube.

Simultaneously, cooling gas such as external air, nitrogen gas, etc., may be supplied to the space between the side cover and the reaction tube to cool the reaction tube, thereby controlling the unloading temperature of the substrate boat.

(90) In step **S300**, the substrate boat may be unloaded from the reaction tube having the temperature of no more than the set temperature. When the reaction tube is cooled to no more than the set temperature after controlling the unloading temperature of the substrate boat, the substrate boat may be unloaded from the reaction tube.

(91) FIG. 4B is a flow chart, illustrating a process for cooling a reaction tube, in accordance with example embodiments.

(92) Referring to FIG. 4B, in step **S210**, the cooling gas may be supplied to the upper region of the space between the side cover and the reaction tube at the first supply rate. In step **S220**, the cooling gas may be supplied to the lower region of the space at the second supply rate, different from the first supply rate. In step **S230**, the cooling gas may be exhausted from the space between the side cover and the reaction tube.

(93) Particularly, in step **S210**, the cooling gas may be supplied to the upper region of the space, between the side cover and the reaction tube, at the first supply rate. The cooling gas may be supplied to the upper region of the space, between the side cover and the reaction tube, through the first gas supplier connected to the upper portion of the side cover. The cooling gas may be supplied to the portion of the upper region in the space between the side cover and the reaction tube.

(94) Particularly, in step **S220**, the cooling gas may be supplied to the lower region of the space at the second supply rate, different from the first supply rate. The cooling gas may be supplied to the lower region of the space between the side cover and the reaction tube through the second gas supplier connected to the lower portion of the side cover at the second supply rate different from the first supply rate. The cooling gas may be supplied to the rest of the lower region in the space between the side cover and the reaction tube.

(95) Therefore, different amounts of the cooling gas may be supplied to the upper region and the lower region in the reaction tube to maintain the temperature uniformity in the reaction tube during the cooling of the reaction tube. Further, the supplying amounts of the cooling gas to the upper region and the lower region in the reaction tube may be controlled to effectively cool the reaction tube, in accordance with the temperature distribution of the reaction tube. Furthermore, the temperature deviation between the regions in the reaction tube may be decreased during cooling the reaction tube.

(96) Particularly, in step **S230**, the cooling gas may be exhausted from the space between the side cover and the reaction tube. The cooling gas in the side cover may be exhausted through the radiant exhauster, connected to the lid, on the side cover. Because the hot air may be positioned in the upper region of the reaction tube due to convection, the heat may be effectively exhausted using the upwardly increasing hot air absorbing the heat in the reaction tube.

(97) The amount of the cooling gas supplied to the upper region may be larger than the amount of the cooling gas supplied to the lower region. Because the hot air may stay for a longer time in the upper region compared to the hot air in the lower region due to convection, and the position of the radiant exhauster, configured to exhaust the cooling gas through the upper portion of the side cover,

the upper region may be cooled relatively slower than the lower region. In contrast, because the cold air may stay in the lower region, where the hot air may be upwardly moved to the upper region, the lower region may be cooled relatively faster than the upper region. Thus, when the amount of the cooling gas supplied by the first gas supplier is substantially the same as or lower than the amount of the cooling gas supplied by the second gas supplier, the lower region of the reaction tube may be cooled relatively quickly to generate the temperature difference between the upper region and the lower region in the reaction tube. In this case, the substrates may have different temperatures in accordance with the positions of the substrates in the reaction tube so that layers on the substrates may have different characteristics. As a result, a uniform layer might not be formed on the substrates.

(98) In example embodiments, because the supplying amount of the cooling gas by the first gas supplier, positioned at the upper region of the reaction tube, may be greater than that of the second gas supplier positioned at the lower region of the reaction tube, the cooling rate (cooling speed) of the upper region in the reaction tube may be improved to decrease the difference between the cooling speed in the upper region and the lower region of the reaction tube. Further, the temperature deviation between the upper region and the lower region in the reaction tube, which may be caused by cooling the lower region of the reaction tube relatively faster, may be prevented. Therefore, the substrate-processing step may be performed on the substrates in the reaction tube to obtain the uniform layer from the substrates.

(99) FIG. 4C is a flow chart, illustrating a process for cooling a reaction tube, in accordance with example embodiments.

(100) Referring to FIG. 4C, the method of cooling the reaction tube may further include measuring the temperatures of the vertically is arranged regions in the reaction tube in step S240 and supplying the thermal energy to the specific region among the regions, having a relatively low temperature, in accordance with the temperatures of the regions in step S250.

(101) Particularly, in step S240, the temperatures of the vertically arranged regions in the reaction tube may be measured.

(102) The temperatures of the regions in the reaction tube may be measured using the temperature sensor to obtain the temperature distribution by the regions.

(103) In step S250, the thermal energy may be supplied to the specific region, having the relatively low temperature, among the regions, in accordance with the measured temperatures of the regions. The thermal energy may be supplied to the specific region, having the relatively low temperature, in accordance with the temperatures of the regions, measured by the temperature sensor to reduce the temperature deviation between the regions.

(104) The process for supplying the thermal energy to the specific region, having the relatively low temperature, in step S250, may include driving the heating member, corresponding to the specific region having the relatively low temperature, using the heater, including the heating members, divided by regions in step S251.

(105) In step S251, the heating member, corresponding to the specific region, having the relatively low temperature, may be controlled by using the heater, including the heating members with is divided regions. The heating member may be controlled or driven using the heater to supply the thermal energy to the specific region having the relatively low temperature. Because the hot air in the lower region of the reaction tube may be upwardly moved due to convection, and the cold air may be positioned in the lower region, the temperature deviation between the upper region and the lower region in the reaction tube may be generated without the driving of the heater. The heating member, measured by the temperature sensor, may be driven using the heater to independently supply the thermal energy to the specific region, having the relatively low temperature, thereby minimizing the temperature deviation between the regions of the reaction tube.

(106) Cooling the reaction tube, in step S200, may further include measuring the exhaust pressure and/or the exhaust speed of the cooling gas in step S260, determining whether the measured

exhaust pressure and/or the measured exhaust speed of the cooling gas may be beyond the set value or not in step **S270**, and decreasing the exhaust pressure and/or the exhaust speed of the cooling gas to no more than the set value when the measured exhaust pressure and/or the measured exhaust speed is beyond the set value in step **S280**.

(107) Particularly, in step **S260**, the exhaust pressure and/or the exhaust speed of the cooling gas may be measured. The exhaust pressure and/or the exhaust speed of the cooling gas may be measured using the exhaust measurement member, connected to the radiant exhauster. Because an exhaust amount may be changed, in accordance with the supply amount of the cooling gas, the exhaust pressure and/or the exhaust speed of the cooling gas may be measured to recognize the exhaust intensity. The exhaust pressure and/or the exhaust speed of the cooling gas may be measured using the output value of the blower in the radiant exhauster. Alternatively, the exhaust pressure and/or the exhaust speed of the cooling gas may be measured by installing the sensor on the exhaust pipe of the radiant exhauster.

(108) In step **S270**, whether the measured exhaust pressure and/or the measured exhaust speed of the cooling gas may be beyond the set value or not may be determined. Whether the measured exhaust pressure and/or the measured exhaust speed of the cooling gas may be beyond the set value or not may be determined by using the controller to maintain the exhaust pressure and/or the exhaust speed of no more than the set value.

(109) In step **S280**, the exhaust pressure and/or the exhaust speed of the cooling gas to no more than the set value may be decreased when the measured exhaust pressure and/or the measured exhaust speed is beyond the set value. When the exhaust pressure and/or the exhaust speed of the radiant exhauster is beyond the set value, stresses applied to the byproducts on the inner surface of the reaction tube may be increased to generate a crack in the byproducts. Thus, particles may be generated from the crack in the reaction tube. In order to prevent the generation of the particles, the exhaust pressure and/or the exhaust speed of the radiant exhauster may be monitored and controlled through the exhaust measurement member to prevent the crack and the lamination of the byproducts in the reaction tube and to improve the cooling speed compared to the natural cooling speed.

(110) Based on example embodiments, the supplying amounts of the cooling gas to the upper region and the lower region in the reaction tube may be different from each other in accordance with the temperature distribution of the reaction tube to effectively cool the reaction tube and to reduce the temperature deviation between the regions of the reaction tube. That is, because the hot air may be positioned in the upper region due to convection, the relatively large amount of the cooling air may be supplied to the upper region of the reaction tube to effectively cool the reaction tube. In contrast, the relatively small amount of the cooling air may be supplied to the lower region of the reaction tube to prevent the lower region from being relatively rapidly cooled, thereby reduce the temperature deviation between the upper region and the lower region in the reaction tube. Further, because the hot air in the lower region of the reaction tube may be upwardly moved due to convection and the cold air may be positioned in the lower region, the temperature deviation between the upper region and the lower region in the reaction tube may be generated without the driving of the heater. The heating member corresponding to the specific region having the relatively low temperature in accordance with the temperatures of the regions is measured by the temperature sensor may be driven using the heater including the heating members divided the regions to independently supply the thermal energy to the specific region having the relatively low temperature, thereby minimizing the temperature deviation between the regions of the reaction tube. Furthermore, the exhaust pressure and/or the exhaust speed of the cooling gas may be maintained under no more than the set value to prevent the crack and the lamination of the byproducts in the reaction tube and to improve the cooling speed compared to the natural cooling speed.

(111) The above described embodiments of the present invention are intended to illustrate and not

to limit the present invention. Various alternatives and equivalents are possible. The invention is not limited by the embodiments described herein. Nor is the invention limited to any specific type of semiconductor device. Another addition, subtractions, or modifications are obvious in view of the present disclosure and are intended to fall within the scope of the appended claims.

Claims

1. An apparatus for processing a substrate, the apparatus including an internal space divided into a plurality of sub-spaces in a vertical direction, the apparatus comprising: a reaction tube arranged at the internal space, the reaction tube that processes a plurality of substrates stacked in the vertical direction; a side cover arranged to surround the reaction tube, the side cover including a plurality of gas transmission holes arranged along the vertical direction at a selected portion of the side cover; and a heater arranged between the reaction tube and the side cover, the heater including a plurality of unit heaters for each of the plurality of sub-spaces, the plurality of unit heaters separated by a plurality of first holes, wherein each of the unit heaters includes an adiabatic block for surrounding the reaction tube, the adiabatic block including a plurality of second holes radially formed therein and divided into a plurality of adiabatic regions; and a coil arranged on an inner surface of the adiabatic block, wherein a cooling gas is transmitted through the plurality of first holes and the plurality of second holes, and temperature of the adiabatic block is lowered by the cooling gas flowing through the plurality of first and second holes.
2. The apparatus of claim 1, further comprising: a cooling gas supplier that supplies a first amount of cooling gas to an upper portion of the internal space and supplies a second amount of the cooling gas smaller than the first amount to a lower portion of the internal space.
3. The apparatus of claim 1, further comprising: a first gas supplier that supplies the cooling gas to an upper portion of the internal space, the first gas supplier including a first duct installed outside of the side cover to define a first external cooling space between the side cover and the first duct, and at least one first gas line connected to the first duct to transmit injected cooling gas to the first external cooling space; and a second gas supplier that supplies the cooling gas to the lower portion of the internal space, the second gas supplier including a second duct installed outside of the side cover under the first duct to define a second external cooling space between the side cover and the second duct, and at least one second gas line connected to the second duct to transmit injected cooling gas to the second external cooling space.
4. The apparatus of claim 3, wherein the first duct and the second duct are installed to cover the plurality of gas transmission holes arranged in the side cover, wherein the cooling gas in the first and second external cooling spaces transmits to inside of the side cover through the plurality of gas transmission holes.
5. The apparatus of claim 3, wherein a length of the first duct is longer than a length of the second duct.
6. The apparatus of claim 3, wherein the number of first transmission holes covered by the first duct is greater than the number of transmission holes covered by the second duct.
7. The apparatus of claim 3, further comprising: an exhauster installed on the side cover, the exhauster including a first exhaust line communicating with the internal space and a second exhaust line.
8. The apparatus of claim 7, wherein a diameter of the first exhaust line is greater than a diameter of the first gas line and a diameter of the second gas line.
9. The apparatus of claim 7, further comprising: a lid that seals an opened upper surface of the side cover, wherein the first exhaust line is inserted into the lid.
10. The apparatus of claim 1, further comprising: a controller that controls a cooling rate of the reaction tube.
11. The apparatus of claim 10, further comprising at least one temperature sensor that measures

temperatures of the plurality of sub-spaces.

12. The apparatus of claim 10, wherein the controller receives measured temperatures from the temperature sensor to independently control the plurality of unit heaters based on the measured temperatures.

13. The apparatus of claim 12, wherein each of the unit heaters further includes an adhesion pattern for bonding the adiabatic block and the side cover.

14. The apparatus of claim 13, wherein a thickness of the adhesion pattern is shallower than a thickness of the adiabatic block.
