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APPARATUS AND METHOD FOR DRYING SUBSTRATE

Abstract

Provided is a substrate drying apparatus. The substrate drying apparatus may include an upper chamber body including an inlet configured to introduce a supercritical fluid into a chamber space, a lower chamber body including an outlet configured to discharge the supercritical fluid outside the chamber space, and a stage configured to be loaded with a wet substrate and arranged in the chamber space, wherein the upper chamber body and the lower chamber body are configured such that the chamber space is closed by bringing the upper chamber body into contact with the lower chamber body, and the chamber space is opened by separating the upper chamber body from the lower chamber body, and the stage comprises a heater configured to heat the substrate and the supercritical fluid.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a divisional of U.S. patent application Ser. No. 17/582,620, filed on Jan. 24, 2022, which is based on and claims priority under 35 U.S.C. § 119 to Korean Patent Application No. 10-2021-0090548, filed on Jul. 9, 2021, in the Korean Intellectual Property Office, the disclosures of which are incorporated herein by reference in their entirety.

BACKGROUND

[0002] The inventive concept relates to an apparatus and method for drying a substrate. More particularly, the inventive concept relates to an apparatus and method for drying a substrate during an extreme ultraviolet (EUV) lithography process after a developing operation.

[0003] In accordance with demands for miniaturization of semiconductor devices, the EUV lithography method having a very short wavelength (about 13.5 nm) has been suggested. When the EUV lithography method is used, a photoresist pattern having a small horizontal dimension and a high aspect ratio (height/horizontal dimension) may be formed. In the related art, the substrate is rotated at a high speed to remove liquid remaining on the substrate after the developing operation. However, due to surface tension of the liquid, the photoresist pattern having a high aspect ratio may collapse. Therefore, alternatively, a method of removing the liquid remaining on the substrate by using supercritical fluid has been suggested.

SUMMARY

[0004] The inventive concept provides a substrate drying apparatus for a wafer to have a uniform temperature distribution for photoresist patterns to have uniform dimensions, and a substrate drying method.

[0005] According to an aspect of the inventive concept, there is provided a substrate drying apparatus including an upper chamber body including an inlet configured to introduce a supercritical fluid into a chamber space, a lower chamber body including an outlet configured to discharge the supercritical fluid outside the chamber space, and a stage in the chamber space and configured to receive a wet substrate, wherein the upper chamber body and the lower chamber body are configured such that the chamber space is closed by bringing the upper chamber body into contact with the lower chamber body, and the chamber space is opened by separating the upper chamber body from the lower chamber body, and the stage includes a heater configured to heat the substrate and the supercritical fluid.

[0006] According to another aspect of the inventive concept, there is provided a substrate drying apparatus including an upper chamber body including an inlet configured to introduce a supercritical fluid into a chamber space, a lower chamber body including an outlet configured to discharge the supercritical fluid outside the chamber space, a plurality of coupling units configured to bring the upper chamber body into contact with the lower chamber body, and a stage configured to be loaded with a wet substrate and arranged in the chamber space, wherein the stage includes an insulating structure and a heater, a heater controller, a battery, and a wireless charging module in the insulating structure, and a coating layer surrounding the insulating structure.

[0007] According to another aspect of the inventive concept, there is provided a method of drying a substrate, the method including loading a wet substrate on a stage, loading the stage on a lower chamber body, contacting the lower chamber body with an upper chamber body to close a chamber space defined by an upper chamber body and the lower chamber body, introducing a supercritical fluid into the chamber space via an inlet in the upper chamber body, heating the substrate and the supercritical fluid by using a heater in the stage, discharging the supercritical fluid outside the chamber space via an outlet in the lower chamber body, opening the chamber space such that the upper chamber body is separated from the lower chamber body, unloading the stage from the lower chamber body, and unloading the substrate from the stage.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Embodiments of the inventive concept will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings in which:

[0009] FIG. **1** is a flowchart illustrating an extreme ultraviolet (EUV) lithography operation according to an embodiment of the inventive concept.

[0010] FIGS. **2**A to **2**F are cross-sectional views illustrating an EUV lithography process according to an embodiment of the inventive concept.

[0011] FIG. **3** is a conceptual diagram illustrating a substrate drying system according to an embodiment of the inventive concept.

[0012] FIG. **4** is a cross-sectional view showing a substrate drying apparatus according to an embodiment of the inventive concept.

[0013] FIG. **5**A is a plan view showing a heater according to an embodiment of the inventive concept.

[0014] FIG. **5**B is a plan view showing a heater according to an embodiment of the inventive concept.

[0015] FIG. **6** is a flowchart illustrating a substrate drying method according to an embodiment of the inventive concept.

[0016] FIGS. **7**A to **7**I are cross-sectional views illustrating a substrate drying method according to an embodiment of the inventive concept.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0017] FIG. **1** is a flowchart illustrating an extreme ultraviolet (EUV) lithography process **1000** according to an embodiment of the inventive concept. FIGS. **2**A to **2**F are cross-sectional views illustrating the EUV lithography process **1000** according to an embodiment of the inventive concept.

[0018] Referring to FIGS. **1** and **2**A, an EUV resist layer PR may be formed on a substrate SB (S**1100**). For example, the EUV resist layer PR on the substrate SB may be formed by spin coating. Thereafter, prebaking may be performed to remove excess organic solvent and stabilize the EUV resist layer PR. The EUV resist layer PR may be sensitive to EUV light. In some embodiments, a thickness T**1** of the EUV resist layer PR may be about 200 nm to about 600 nm, but a thicker or thinner EUV resist layer PR may be used.

[0019] In some embodiments, the EUV resist layer PR may include a polymer-based chemically amplified resist (CAR). In general, polymer-based CARs may include a backbone matrix polymer, a photoacid generator (PAG), and a dissolution inhibitor. The backbone matrix polymer may include poly(4-hydroxystyrene) (PHS), styrene derivatives, acrylate copolymers, or a combination thereof. Polymer-based CARs may further include non-metallic elements such as fluorine.

[0020] In some embodiments, the EUV resist layer PR may include a molecular glass resist. The molecular glass resist may include, for example, phenolic compounds, calixarene derivatives, or a combination thereof. In some embodiments, the EUV resist layer PR may include an inorganic-based resist. The inorganic base resist may include, for example, a TiO.sub.2-based resist, a ZrO.sub.2-based resist, a Ta.sub.2O.sub.5-based resist, an HfO.sub.2-based resist, and the like.

[0021] Referring to FIGS. **1** and **2**B, a portion of the EUV resist layer PR may be exposed to EUV light LG. The EUV light LG may have a wavelength of about 13.5 nm. The mask MK may selectively reflect EUV light LG such that a portion of the EUV resist layer PR is selectively exposed to EUV light LG. Thereafter, post exposure baking may be performed.

[0022] The mask MK may include a silicon substrate **204**. The mask MK may further include a multilayer **203** including a plurality of silicon layers stacked alternately with a plurality of molybdenum layers on the silicon substrate **204**. In some embodiments, the thickness of each molybdenum layer may be different from the thickness of each silicon layer. The mask MK may further include a ruthenium layer **202** on the multilayer **203**. The mask MK may further include layout patterns **201** on the ruthenium layer **202**. The layout patterns **201** may include a tantalum boron nitride (TABN) layer and a lawrencium layer. Other materials and configurations of layers may be used in alternative masks MK. In addition, the mask MK may further include various layers.

[0023] EUV light LG generated from a light source may be incident on the mask MK in an oblique angle. The angle θ between EUV light LB incident on the mask MK and a direction perpendicular to the mask MK may be from about 5 degrees to about 7 degrees. The EUV light LG reflected by the mask MK may be incident on the EUV resist layer PR.

[0024] Referring to FIGS. **1**, **2**B, and **2**C, an EUV resist pattern PRP may be formed by partially removing the EUV resist layer PR by using a developing solution (S**1300**). In some embodiments, when the EUV resist is a negative type, a portion of the EUV resist layer PR exposed to light may remain and a portion of the EUV resist layer PR not exposed to light may be removed. In other embodiments, when the EUV resist is a positive type, a portion of the EUV resist layer PR exposed to light may be removed and a portion of the EUV resist layer PR not exposed to light may remain. After developing, liquid RL may remain on the substrate SB and the EUV resist pattern PRP. The liquid RL may include a developing solution, water, and/or an organic solvent.

[0025] Referring to FIGS. **1**, **2**C, and **2**D, the liquid RL may be removed from the substrate SB and the EUV resist pattern PRP. Thus, the substrate SB and the EUV resist pattern PRP may be dried (S**1400**). In the related art, a method of rotating the substrate SB at a high speed to remove liquid RL from the substrate SB and the EUV resist pattern PRP is used. However, the finer the EUV resist pattern PRP becomes, the EUV resist pattern PRP may collapse during rotation at a high speed because of surface tension caused by a high aspect ratio of the EUV resist pattern PRP.

[0026] In order to solve such a problem, a method of removing liquid RL by using a supercritical fluid has been suggested. By dissolving the liquid RL in the supercritical fluid and discharging the supercritical fluid, the liquid RL may be removed from the substrate SB and the EUV resist pattern PRP together with the supercritical fluid. A drying system using the supercritical fluid is described with reference to FIG. **3**, a drying apparatus using the supercritical fluid is described with reference to FIG. **4**, and a drying method using the supercritical fluid is described with reference to FIGS. **6** and **7**A to **7**G.

[0027] Referring to FIGS. **1** and **2**E, by using the EUV resist pattern PRP as an etching mask, a layer below the EUV resist pattern PRP, for example, the substrate SB, may be etched (S**1500**). Accordingly, a pattern PT may be formed in the substrate SB. When a material layer is located between the EUV resist pattern PRP and the substrate SB, the pattern PT in the material layer may be formed by etching the material layer by using the EUV resist pattern PRP as the etching mask. Depending on the material to be etched, various etching methods such as wet etching or dry etching may be performed. A dry etching method may include, for example, reactive ion etching (RIE).

[0028] Referring to FIGS. **1**, **2**E, and **2**F, the EUV resist pattern PRP may be removed from the substrate SB.

[0029] FIG. **3** is a conceptual diagram illustrating a substrate drying system **10** according to an embodiment of the inventive concept.

[0030] Referring to FIG. **3**, the substrate drying system **10** may include a liquid tank **11**, a condenser **14**, a pump **15**, a storage tank **16**, a heater **17**, a substrate drying apparatus **100**, and a discharging apparatus **19**. The substrate drying system **10** may further include a plurality of filters, for example, first to third filters **12***a* to **12***c*, and a plurality of valves, for example, first to third valves **13***a* to **13***c*.

[0031] The liquid tank **11** may store liquid, for example, liquid carbon dioxide. The condenser **14** may convert supercritical fluid or gas into liquid and remove impurities therefrom. The pump **15** may convert liquid into supercritical fluid by applying pressure equal to or greater than supercritical pressure to the liquid. The storage tank **16** may store the supercritical fluid. The heater **17** may maintain a supercritical fluid state by heating the supercritical fluid to maintain a temperature of the supercritical fluid at a temperature equal to or greater than a critical temperature. The supercritical fluid may be supplied to the substrate drying apparatus **100**. In the substrate drying apparatus **100**, the supercritical fluid may dry the substrate. The supercritical fluid may dissolve the liquid on the substrate. The substrate drying apparatus **100** is described in more detail with reference to FIG. **4**. The supercritical fluid in which liquid is dissolved may be discharged from the substrate drying apparatus **100** by the discharging apparatus **19**.

[0032] The first to third filters **12***a* to **12***c* may remove impurities from the liquid or the supercritical fluid. Although FIG. **3** shows that the substrate drying system **10** includes three filters, for example, the first to third filters **12***a* to **12***c*, the substrate drying system **10** may include more or less than three filters.

[0033] The first to third valves **13***a* to **13***c* may control a flow of the liquid or the supercritical fluid. Although FIG. **3** shows that the substrate drying system **10** includes three valves, for example, the first to third valves **13***a* to **13***c*, the substrate drying system **10** may include more or less than three valves.

[0034] FIG. **4** is a cross-sectional view showing a substrate drying apparatus **100** according to an embodiment of the inventive concept. FIG. **5**A is a plan view showing a heater **139** according to an embodiment of the inventive concept. FIG. **5**B is a plan view showing a heater **139-1** according to an embodiment of the inventive concept.

[0035] Referring to FIGS. **4**, **5**A, and **5**B, the substrate drying apparatus **100** may include an upper chamber body **110**, a lower chamber body **120**, and a stage **130**. The upper chamber body **110** may include an inlet **111** configured to introduce supercritical fluid into a chamber space CS. The upper chamber body **110** may include a ceiling **110***a* and an upper wall **110***b* extending from the ceiling **110***a* toward the lower chamber body **120**. The inlet **111** may penetrate the ceiling **110***a* of the upper chamber body **110**. In some embodiments, the upper chamber body **110** may include stainless steel. The supercritical fluid may include, for example, carbon dioxide in a supercritical fluid state.

[0036] The lower chamber body **120** may include an outlet **121** configured to discharge the supercritical fluid outside the chamber space CS. The lower chamber body **120** may include a floor **120***a* and a lower wall **120***b* extending from the floor **120***a* toward the upper chamber body **110**. The outlet **121** may penetrate the floor **120***a* of the lower chamber body **120**. In some embodiments, the lower chamber body **120** may include stainless steel.

[0037] The upper chamber body **110** and the lower chamber body **120** may be configured such that the chamber space CS is closed by bringing the upper chamber body **110** into contact with the lower chamber body **120**, and the chamber space CS is opened by separating the upper chamber body **110** from the lower chamber body **120**. That is, the upper chamber body **110** and the lower chamber body **120** may form an open-type chamber body. The upper wall **110***b* of the upper chamber body **110** and the lower wall **120***b* of the lower chamber body **120** may be in contact with each other.

[0038] The substrate drying apparatus **100** may be configured such that a pressure and a temperature in the chamber space CS are equal to or greater than a critical pressure and a critical temperature of the supercritical fluid, respectively. For example, the critical pressure of carbon dioxide may be about 74 bar and the critical temperature thereof may be about 31° C. The temperature in the chamber space CS may be, for example, about 31° C. to about 100° C., and the pressure in the chamber space CS may be about 74 bar to about 100 bar.

[0039] The stage **130** may be loaded with the substrate SB and arranged in the chamber space CS. The stage **130** may include the substrate SB and the heater **139** configured to heat the supercritical fluid. The stage **130** may further include a heater controller **137***a* for controlling the heater **139**.

[0040] In some embodiments, as shown in FIG. **5**A, the heater **139** may include a plurality of heating zones HZ arranged in a first direction (X direction) and a second direction (Y direction), wherein the first direction and the second direction intersect each other. In some embodiments, the first direction (X direction) and the second direction (Y direction) may be perpendicular to each other. Although FIG. **5**A shows that the heater **139** includes **64** heating zones HZ, the number of heating zones HZ that the heater **139** may include may be greater than or less than **64**. In some embodiments, for uniform heating, a dimension L**1** in the first direction (X direction) of the heater **139** and a dimension L**2** in the second direction (Y direction) of the heater **139** may each be greater than a diameter DO of the substrate SB. For example, when the diameter DO of the substrate SB is 300 mm, the dimension L**1** in the first direction (X direction) of the heater **139** (X direction) and the dimension L**2** in the second direction (Y direction) of the heater **139** may each be 300 mm or more.

[0041] The heater controller **137***a* may independently control the plurality of heating zones HZ. The heater controller **137***a* may independently control a voltage or current that is transferred to the plurality of heating zones HZ. The heater controller **137***a* may control the plurality of heating zones HZ so that the substrate SB has a uniform temperature across the substrate SB. According to a simulation result, when uniform power is provided to the plurality of heating zones HZ, a temperature in the center of the substrate SB is lower than a temperature in the outermost portion of the substrate SB. Accordingly, the heater controller **137***a* may control central heating zones HZa and outermost heating zones HZb among the plurality of heating zones HZ such that power consumed by the central heating zones HZa is greater than power consumed by the outermost heating zones HZb.

[0042] As used herein, the central heating zones HZa refer to the closest ones to the center of the heater **139** among the plurality of heating zones HZ, and the outermost heating zones HZb refer to the farthest ones from the center of the heater **139** among the plurality of heating zones HZ. When the heater **139** includes 2n (n is a natural number) heating zones HZ in the first direction (X direction) and 2n heating zones HZ in the second direction (Y direction), the central heating zones HZa may refer to the heating zones HZ having coordinates of (n, n), (n, n+1), (n+1, n), or (n+1, n+1) in the first direction (X direction) and the second direction (Y direction). The outermost heating zones HZb may refer to the heating zones HZ having coordinates of (2n, 1), (1, 1), (1, 2n), or (2n, 2n) in the first direction (X direction) and the second direction (Y direction). When the heater **139** includes 2n+1 (n is a natural number) heating zones HZ in the first direction (X direction) and 2n+1 heating zones HZ in the second direction (Y direction), the central heating zone HZa may refer to the heating zones HZ having coordinates of (n+1, n+1) in the first direction (X direction) and the second direction (Y direction). The outermost heating zone HZb may refer to the heating zones HZ having coordinates of (2n+1, 1), (1, 1), (1, 2n+1), or (2n+1, 2n+1) in the first direction (X direction) and the second direction (Y direction).

[0043] In some embodiments, as shown in FIG. **5**B, the heater **139-1** may include a plurality of heating zones HZ-**1** arranged in a radial direction (R direction) of the heater. Although FIG. **5**B shows that the heater **139-1** includes six heating zones HZ-**1**, the number of heating zones HZ-**1** that the heater **139-1** may include may be greater than or less than six. In some embodiments, for uniform heating, a diameter D**1** of the heater **139-1** may be greater than the diameter D**0** of the substrate SB. For example, when the diameter D**0** of the substrate SB is 300 mm, the diameter D**1** of the heater **139-1** may be 300 mm or more. A central heating zone HZa-**1** among the plurality of heating zones HZ-**1** may be circular. The remaining heating zones HZ-**1** may have a shape of a ring having the same center as the central heating zone HZa-**1**.

[0044] The heater controller **137***a* may independently control the plurality of heating zones HZ-**1**. The heater controller **137***a* may independently control voltage or current that is transferred to the plurality of heating zones HZ-**1**. The heater controller **137***a* may control the plurality of heating zones HZ-**1** so that the substrate SB has a uniform temperature across the substrate SB. According to the simulation result, when uniform power is provided to the plurality of heating zones HZ-**1**, the temperature in the center of the substrate SB is lower than the temperature in the outermost portion of the substrate SB. Accordingly, the heater controller **137***a* may control the central heating zone HZa-**1** and an outermost heating zone HZb-**1** among the plurality of heating zones HZ-**1** such that power consumed by the central heating zone HZa-**1** is greater than power consumed by the outermost heating zone HZb-**1**.

[0045] The heaters **139** and **139-1** may heat the substrate SB so that the substrate SB has a relatively uniform temperature across the substrate SB. Therefore, a difference in the dimension of the EUV resist pattern caused by a change in the temperature of the substrate SB may be reduced.

[0046] The stage **130** may further include a battery **135** for supplying power to the heaters **139** and **139-1** and a wireless charging module **136** for wirelessly charging the battery **135**. Therefore, power may be supplied to the heater **139** without complicated wiring for connecting the heater **139** to a power source. The battery **135** may include a lithium ion battery in some embodiments. The wireless charging module **136** may be inductive or resonant.

[0047] The stage **130** may further include temperature sensors, for example, first and second temperature sensors **138***a* and **138***b*. The heater controller **137***a* may control the heaters **139** and **139-1** according to the temperature sensor, for example, the first and second temperature sensors **138***a* and **138***b*. For example, the first temperature sensor **138***a* may be disposed under the central heating zones HZa and HZa-**1** and the second temperature sensor **138***b* may be disposed under the outermost heating zones HZb and HZb-**1**. The heater controller **137***a* may control the heaters **139** and **139-1** such that a difference between a first temperature of the first temperature sensor **138***a* and a second temperature of the second temperature sensor **138***b* is reduced. The heater controller **137***a* may control the heaters **139** and **139-1** such that a difference between a first temperature of the first temperature sensor **138***a* and a second temperature of the second temperature sensor **138***b* is within a certain range.

[0048] The number and arrangement of the temperature sensors may vary. In some embodiments, the stage **130** may include only one temperature sensor. The heater controller **137***a* may control the heaters **139** and **139-1** such that the temperature of the temperature sensor is within a certain range.

[0049] In another embodiment, the stage **130** may include a number of temperature sensors corresponding to the number of heating zones HZ and HZ-**1**. The heater controller **137***a* may control the plurality of heating zones HZa-**1** and HZb-**1** to reduce the difference between the temperatures of the plurality of temperature sensors. The heater controller **137***a* may control the heaters **139** and **139-1** such that the temperature of each temperature sensor is within a certain range.

[0050] In some embodiments, the stage **130** may further include a controller **137***b* for controlling an entire circuit including the heaters **139** and **139-1**, the battery **135**, the wireless charging module **136**, the first and second temperature sensors **138***a* and **138***b*, and the heater controller **137***a*. For example, the controller **137***b* may turn on the wireless charging module **136** to charge the battery

135, and turn off the heaters **139** and **139-1**. Also, the controller **137***b* may turn off the wireless charging module **136**, and turn on the heaters **139** and **139-1**.

[0051] The stage **130** may include a first insulating layer **133** and a second insulating layer **132** under the first insulating layer **133**. The first insulating layer **133** and the second insulating layer **132** may form an insulating structure IS. The first insulating layer **133** may cover the heater **139**. The second insulating layer **132** may cover at least one of the battery **135**, the wireless charging module **136**, the heater controller **137***a*, the controller **137***b*, and the first and second temperature sensors **138***a* and **138***b*. Thus, the heater **139** may be located in the insulating structure IS. At least one of the battery **135**, the wireless charging module **136**, the heater controller **137***a*, the controller **137***b*, and the first and second temperature sensors **138***a* and **138***b* may be located in the insulating structure IS. Thus, the heater **139** may be surrounded by the insulating structure IS. At least one of the battery **135**, the wireless charging module **136**, the heater controller **137***a*, the controller **137***b*, and the first and second temperature sensors **138***a* and **138***b* may be surrounded by the insulating structure IS.

[0052] The first insulating layer **133** and the second insulating layer **132** may include, for example, polyether ether ketone (PEEK), polyimide (PI), or polytetrafluoroethylene (PTFE).

[0053] The stage **130** may further include a coating layer **130**C covering the insulating structure IS. That is, the coating layer **130**C may surround the insulating structure IS. The coating layer **130**C may include a material which withstands high temperature and high pressure in the chamber space CS. The coating layer **130**C may include, for example, PTFE.

[0054] In some embodiments, the stage **130** may further include a filler **131** filling a portion of the chamber space CS between the lower chamber body **120** and the second insulating layer **132**. The filler **131** may cause the pressure in the chamber space CS to quickly reach the critical pressure by reducing a volume of the chamber space CS that the supercritical fluid needs to fill. The filler **131** may include, for example, stainless steel.

[0055] The substrate drying apparatus **100** may further include a first lower heater **122** in the floor **120***a* of the lower chamber body **120** and a second lower heater **123** in the lower wall **120***b* of the lower chamber body **120**. In some embodiments, the first lower heater **122** may have a bar shape. In some embodiments, the second lower heater **123** may be ring-shaped or coil-shaped and may surround the chamber space CS.

[0056] The substrate drying apparatus **100** may further include a first upper heater **112** in the ceiling **110***a* of the upper chamber body **110** and a second upper heater **113** in the upper wall **110***b* of the upper chamber body **110**. In some embodiments, the first upper heater **112** may have a bar shape. In some embodiments, the second upper heater **113** may be ring-shaped or coil-shaped and may surround the chamber space CS.

[0057] In some embodiments, the lower chamber body **120** may further include one or more supporting structures, such as one or more pins **120***c* protruding from the upper surface of the floor **120***a* toward the stage **130**. The stage **130** may be loaded on the pins **120***c*. In some embodiments, the stage **130** may further include one or more supporting structures, such as one or more substrate pins **134** on the first insulating layer **133**. The substrate SB may be loaded on the substrate pins **134**.

[0058] In some embodiments, the substrate drying apparatus **100** may further include a plurality of coupling units **140** configured to bring the upper chamber body **110** into contact with the lower chamber body **120**. The coupling units **140** may bring the upper wall **110***b* of the upper chamber body **110** into contact with the lower wall **120***b* of the lower chamber body **120**. The coupling units **140** may contact inclined portions of the upper chamber body **110** and the lower chamber body **120**, respectively. By applying force to the coupling units **140** in a horizontal direction toward the center portion of the substrate drying apparatus **100**, force may be applied downwards and upwards to the upper chamber body **110** and the lower chamber body **120**, respectively. Thus, the upper chamber body **110** and the lower chamber body **120** may be in stronger contact with each other.

[0059] FIG. **6** is a flowchart illustrating a substrate drying method S**1400** according to an embodiment of the inventive concept. FIGS. **7**A to **7**I are cross-sectional views illustrating the substrate drying method S**1400** according to an embodiment of the inventive concept.
[0060] Referring to FIGS. **6** and **7**A, the battery **135** in the stage **130** may be wirelessly charged (S**1401**). The stage **130** may be disposed adjacent to the wireless charger RC to wirelessly charge the battery **135**. For example, the battery **135** may be placed on the wireless charger RC. However, the stage **130** may not necessarily contact the wireless charger RC. For example, the stage **130** may be separated from the wireless charger RC. The battery **135** may be wirelessly charged using the wireless charging module **136** in the stage **130**. Because the battery **135** in the stage **130** is wirelessly charged, a complex wiring for providing power to the stage **130** may be unnecessary. In some embodiments, operation S**1401** of wirelessly charging the battery **135** may be performed at the end of the substrate drying method S**1400**. That is, operation S**1401** of wirelessly charging the battery **135** may be performed after operation S**1490** of unloading the substrate SB from the stage **130**.
[0061] Referring to FIGS. **6** and **7**B, a wet substrate SB may be loaded on the stage **130** (S**1410**). The wet substrate SB may be a substrate SB that underwent a developing operation. A liquid, such as a developing solution, water, and an organic solvent, etc. may remain on the substrate SB. The substrate SB may be loaded on the substrate pins **134** of the stage **130**.
[0062] Referring to FIGS. **6** and **7**C, the stage **130** may be loaded on the lower chamber body **120** (S**1420**). For example, the stage **130** may be loaded on the pins **120***c* of the lower chamber body **120**.
[0063] Referring to FIGS. **6** and **7**D, the chamber space CS may be closed (S**1430**). For example, the chamber space CS defined by the upper chamber body **110** and the lower chamber body **120** may be closed such that the upper chamber body **110** contacts the lower chamber body **120**. The upper wall **110***b* of the upper chamber body **110** may contact the lower wall **120***b* of the lower chamber body **120**. In some embodiments, each coupling unit **140** may additionally contact the inclined portions of the upper chamber body **110** and the lower chamber body **120**, respectively. By moving the coupling units **140** in a horizontal direction toward the center portion of the substrate drying apparatus **100**, force may be applied downwards LD and upwards UD to the upper chamber body **110** and the lower chamber body **120**, respectively. Thus, the upper chamber body **110** may contact the lower chamber body **120** to close the chamber space CS.
[0064] Referring to FIGS. **6** and **7**E, supercritical fluid may be introduced into the chamber space CS S**1440**. The supercritical fluid may be introduced into the chamber space CS via the inlet **111** penetrating the ceiling **110***a* of the upper chamber body **110**. In addition, the substrate SB and the supercritical fluid may be heated by the heater **139** in the stage **130** (S**1450**). In some embodiments, operation S**1440** of introducing the supercritical fluid into the chamber space CS may be performed simultaneously with a heating operation S**1450** or the heating operation S**1450** may be performed before operation S**1440** of introducing the supercritical fluid into the chamber space CS. In some embodiments, operation S**1440** of introducing the supercritical fluid into the chamber space CS and a heating operation S**1450** may be proceeded sequentially. Operation S**1440** of introducing the supercritical fluid into the chamber space CS and the heating operation S**1450** may cause the pressure and temperature in the chamber space CS to be greater than or equal to the critical pressure and critical temperature of the supercritical fluid. For example, the critical pressure of carbon dioxide may be about 74 bar and the critical temperature thereof may be about 31° C. The temperature in the chamber space CS may be, for example, about 31° C. to about 100° C., and the pressure in the chamber space CS may be about 74 bar to about 100 bar.
[0065] In some embodiments, in addition to the heater **139** in the stage **130**, at least one of the first upper heater **112** in the ceiling **110***a* of the upper chamber body **110**, the second upper heater **113** in the upper wall **110***b* of the upper chamber body **110**, the first lower heater **122** in the floor **120***a* of the lower chamber body **120**, and the second lower heater **123** in the lower wall **120***b* of the lower

chamber body **120** may be used to heat the substrate SB and the supercritical fluid.
[0066] As shown in FIG. **5**A, the heater **139** may include a plurality of heating zones HZ arranged in a first direction (X direction) and a second direction (Y direction), wherein the first direction and the second direction intersect each other, for example, are perpendicular to each other. The heater controller **137***a* may independently control the plurality of heating zones HZ. The heater controller **137***a* may independently control a voltage or a current that is transferred to the plurality of heating zones HZ. The heater controller **137***a* may control the plurality of heating zones HZ so that the substrate SB has a uniform temperature across the substrate SB. For example, the heater controller **137***a* may control the central heating zones HZa and the outermost heating zones HZb among the plurality of heating zones HZ such that power consumed by the central heating zones HZa is greater than power consumed by the outermost heating zones HZb.
[0067] In some embodiments, as shown in FIG. **5**B, the heater **139-1** may include a plurality of heating zones HZ-**1** arranged in a radial direction (R direction) thereof. The heater controller **137***a* may independently control the plurality of heating zones HZ-**1**. The heater controller **137***a* may independently control the voltage or the current that is transferred to the plurality of heating zones HZ-**1**. The heater controller **137***a* may control the plurality of heating zones HZ-**1** so that the substrate SB has a uniform temperature across the substrate SB. For example, the heater controller **137***a* may control the central heating zone HZa-**1** and the outermost heating zone HZb-**1** among the plurality of heating zones HZ-**1** such that power consumed by the central heating zone HZa-**1** is greater than power consumed by the outermost heating zone HZb-**1**.
[0068] Referring to FIGS. **6** and **7**F, the supercritical fluid may be discharged outside the chamber space CS (S**1460**). After the supercritical fluid dissolves liquid on the substrate SB, the supercritical fluid may be discharged outside the chamber space CS together with the liquid on the substrate SB. For example, the supercritical fluid may be discharged outside the chamber space CS via the outlet **121** penetrating the floor **120***a* of the lower chamber body **120**.
[0069] Next, referring to FIGS. **6** and **7**G, the chamber space CS may be opened (S**1470**). For example, the plurality of coupling units **140** may be moved to a direction HHD away from the center of the substrate drying apparatus **100**. In addition, the chamber space CS may be opened by separating the upper chamber body **110** from the lower chamber body **120**. For example, the upper chamber body **110** may be moved away from the lower chamber body **120**. Alternatively or additionally, the lower chamber body **120** may be moved away from the upper chamber body **110**.
[0070] Next, referring to FIGS. **6**, **7**H, the stage **130** may be unloaded from the lower chamber body **120** (S**1480**). For example, the stage **130** may be unloaded from the pins **120***c* of the lower chamber body **120**.
[0071] Next, referring to FIGS. **6** and **7**I, the substrate SB may be unloaded from the stage **130** (S**1490**). For example, the substrate SB may be unloaded from the substrate pins **134** of the stage **130**.
[0072] While the inventive concept has been particularly shown and described with reference to embodiments thereof, it will be understood that various changes in form and details may be made therein without departing from the spirit and scope of the following claims.

Claims

1. A method of drying a substrate, the method comprising: loading a wet substrate on a stage; loading the stage on a lower chamber body; contacting the lower chamber body with an upper chamber body to close a chamber space defined by the upper chamber body and the lower chamber body; introducing a supercritical fluid into the chamber space via an inlet in the upper chamber body; heating the substrate and the supercritical fluid by using a heater in the stage; discharging the supercritical fluid outside the chamber space via an outlet in the lower chamber body; and opening the chamber space such that the upper chamber body is separated from the lower chamber body.

2. The method of claim 1, wherein a pressure and a temperature in the chamber space become greater than or equal to a critical pressure and a critical temperature of the supercritical fluid, respectively, by the heating of the substrate and the introducing of the supercritical fluid into the chamber space.
3. The method of claim 1, wherein the heater comprises a plurality of heating zones arranged in a first direction and a second direction, wherein the first direction and the second direction intersect each other, and the method further comprises independently controlling the plurality of heating zones.
4. The method of claim 1, wherein the heater comprises a plurality of heating zones arranged in a radial direction of the heater, and the method further comprises independently controlling the plurality of heating zones.
5. The method of claim 4, wherein the independently controlling the plurality of heating zones comprises controlling a central heating zone and an outermost heating zone among the plurality of heating zones such that power consumed by the central heating zone is greater than power consumed by the outermost heating zone.
6. The method of claim 1, further comprising wirelessly charging a battery in the stage before loading the wet substrate on the stage or after unloading the substrate from the stage.
7. The method of claim 1, wherein the lower chamber body comprises a floor and a lower wall extending from the floor toward the upper chamber body, the upper chamber body comprises a ceiling and an upper wall extending from the ceiling toward the lower chamber body, and the method further comprises heating the substrate and the supercritical fluid with at least one of a first lower heater in the floor, a second lower heater in the lower wall, a first upper heater in the ceiling, and a second upper heater in the upper wall.
8. The method of claim 1, further comprising bringing a plurality of coupling units into contact with the upper chamber body and the lower chamber body, wherein the opening of the chamber space further comprises moving the plurality of coupling units away from the upper chamber body and the lower chamber body; and wherein, after opening the chamber space, the method further comprises: unloading the stage from the lower chamber body; and unloading the substrate from the stage.