DUAL ZONE HEATERS FOR METALLIC PEDESTALS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/554,751, filed on February 16, 2024. The entire disclosure of the application referenced above is incorporated herein by reference.

FIELD

[0002] The present disclosure relates generally to substrate processing systems and more particularly to dual zone heaters for metallic pedestals used to process substrate in substrate processing systems.

BACKGROUND

[0003] The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0004] Substrate processing systems (called tools) are used to process substrates such as semiconductor wafers. A tool comprises multiple process modules (PMs). Each PM comprises multiple stations. Substrates are processed in the stations using different processes such as deposition and etching processes. Each station comprises a substrate support (pedestal) on which a substrate is placed during processing. The pedestal comprises a baseplate and a stem. The stem is connected to a center region of the baseplate. The substrate is placed on the baseplate of the pedestal during processing. Different processes such as atomic layer deposition (ALD), plasma enhanced ALD (PEALD), thermal ALD (T-ALD), chemical vapor deposition (CVD), plasma enhanced CVD (PECVD), and so on may be performed on the substrates in different stations.

SUMMARY

[0005] A substrate support for processing a substrate comprises a baseplate, a first heater arranged in a first portion of the baseplate, and a second heater arranged in a

second portion of the baseplate and partially arranged in the first portion of the baseplate.

[0006] In additional features, the second heater surrounds the first heater, and the second portion surrounds the first portion.

[0007] In additional features, the baseplate is cylindrical, the first portion is circular and comprises a center of the baseplate, the second portion is annular and surrounds the first portion, and the first portion and the second portion are concentric.

[0008] In additional features, the first heater and the second heater are separately controlled.

[0009] In additional features, the first heater and the second heater comprise curved and linear portions.

[0010] In additional features, the first heater and the second heater comprise portions extending in clockwise and counter-clockwise directions.

[0011] In additional features, the first heater and the second heater are symmetric around a diameter of the baseplate.

[0012] In additional features, the baseplate is cylindrical and comprises four quadrants Q1, Q2, Q3, and Q4; and the first heater and the second heater are symmetric around a diameter of the baseplate that separates Q1 and Q4 from Q2 and Q3.

[0013] In additional features, the baseplate is cylindrical and comprises four quadrants Q1, Q2, Q3, and Q4; and portions of the first heater and the second heater in Q1 and Q4 are mirror images of portions of the first heater and the second heater in Q2 and Q3.

[0014] In additional features, the baseplate is cylindrical and comprises four quadrants, and the first heater and the second heater comprise at least two portions extending through at least two of the four quadrants.

[0015] In additional features, the baseplate is cylindrical and comprises four quadrants, and the first heater comprises a semicircular portion extending through first and second quadrants of the four quadrants.

[0016] In additional features, the baseplate is cylindrical and comprises four quadrants, and the first heater comprises two turns in each of the four quadrants.

[0017] In additional features, the baseplate is cylindrical and comprises four quadrants Q1, Q2, Q3, and Q4; the first heater comprises two terminals in Q1 and Q2; and the second heater comprises two terminals in Q3 and Q4.

[0018] In additional features, the second heater comprises two semicircular portions that surround the first heater, and a circular portion that is connected to the two semicircular portions and that surrounds the two semicircular portions.

[0019] In additional features, the baseplate is cylindrical and comprises four quadrants, and the first heater comprises a semicircular portion extending through first and second quadrants of the four quadrants and comprises two turns in each of the four quadrants.

[0020] In additional features, the second heater comprises two semicircular portions that surround the first heater, and a circular portion that is connected to the two semicircular portions and that surrounds the two semicircular portions.

[0021] In additional features, the first heater and the second heater are symmetric around a diameter of the baseplate that intersects only the semicircular portion of the first heater and the circular portion of the second heater.

[0022] In additional features, the first heater and the second heater comprise heating elements having a D-shaped cross-section.

[0023] In additional features, the first heater and the second heater comprise heating elements having a circular cross-section.

[0024] In additional features, the substrate support further comprises a first temperature sensor arranged in the first portion of the baseplate, and a second temperature sensor arranged in the second portion of the baseplate.

[0025] In additional features, the first temperature sensor is removable, and the second temperature sensor is embedded in the second portion of the baseplate.

[0026] In additional features, a system comprises the substrate support and further comprising a controller configured to control the first heater based on a first temperature of the first portion sensed by the first temperature sensor, and to control the second heater based on a second temperature of the second portion sensed by the second temperature sensor.

[0027] In additional features, a system comprises the substrate support and further comprises a third temperature sensor arranged adjacent to the second temperature sensor in the second portion of the baseplate. The system further comprises a controller configured to control the first heater based on a first temperature of the first portion sensed by the first temperature sensor, and to control the second heater based on a second temperature of the second portion sensed by the second temperature sensor or the third temperature sensor.

[0028] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0030] FIG. 1 shows an example of a substrate processing system for processing substrates using a metallic pedestal comprising dual zone heaters according to the present disclosure;

[0031] FIG. 2 shows a transverse section of a baseplate of the metallic pedestal of FIG. 1 showing a top view of two heaters embedded in the baseplate of the metallic pedestal according to the present disclosure;

[0032] FIG. 3 shows zones of the baseplate of the metallic pedestal of FIG. 2 in which the two heaters are embedded according to the present disclosure;

[0033] FIG. 4 shows a layout of a substrate relative to the two heaters when the substrate is placed on the baseplate of the metallic pedestal of FIG. 2 according to the present disclosure;

[0034] FIG. 5 shows a region of the baseplate in contact with a stem of the metallic pedestal of FIG. 2 that is heated by the two heaters according to the present disclosure;

[0035] FIGS. 6A-6C show geometries of the two heaters embedded in the baseplate of the metallic pedestal of FIG. 2 according to the present disclosure;

[0036] FIGS. 7A and 7B show two different implementations of the two heaters in the baseplate of the metallic pedestal of FIG. 2 according to the present disclosure;

[0037] FIG. 8A shows a controller of the substrate processing system of FIG. 1 for controlling power supplied to the two heaters embedded in the baseplate of the metallic pedestal of FIG. 2 according to the present disclosure; and

[0038] FIG. 8B shows a method performed by the controller to independently control the supplied to the two heaters embedded in the baseplate of the metallic pedestal of FIG. 2 according to the present disclosure.

[0039] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0040] Some metallic pedestals comprise a heater to heat the substrate. The heater is disposed in the baseplate of the pedestal. The heater is designed with the expectation to uniformly heat the substrate. However, a single heater cannot uniformly heat the substrate, which causes temperature non-uniformities across the substrate. For example, when a single heater is used to heat the substrate, temperatures at some of the regions of the substrate differ from the temperature of the rest of the substrate. The temperature difference is more pronounced in outer regions of the substrate due to heat lost from the baseplate to the station walls through radiation.

[0041] Further, the turns of the heater are far apart in some places and are too close together in other places. The separation and proximity of the turns tend to not uniformly heat the substrate. The separation of the turns tends to cause cold spots on the substrate. The proximity of the turns tends to cause hot spots on the substrate. Cold spots are regions where the temperatures are less than the temperature of the rest of the substrate by more than a threshold. Hot spots are regions where the temperatures are greater than the temperature of the rest of the substrate by more than a threshold. The temperature non-uniformity causes process defects, which reduces yield.

[0042] The present disclosure provides a dual zone heater system in which the baseplate of the pedestal is divided into an inner zone and an outer zone. The inner zone is circular and extends radially outwards from the center of the baseplate of the pedestal up to about 60-80% of the radius of the baseplate of the pedestal. The outer zone is annular and surrounds the inner zone. The outer zone extends radially inwards from an outer diameter (OD) of the baseplate up to about 15-20% of the radius of the baseplate of the pedestal. A first heater is arranged in the inner zone and can be called

an inner heater. A second heater is arranged in the outer zone and can be called an outer heater. A portion of the outer heater also extends into the inner zone.

[0043] The inner heater has a complex geometry as described below in detail. The inner heater extends radially from the center of the baseplate of the pedestal up to about 60-80% of the radius of the baseplate of the pedestal. The diameter of the substrate is greater than a diameter of the inner zone in which the inner heater lies. The outer heater is generally circular. The outer heater can comprise one or more turns. The outer heater is arranged proximate to an outer diameter (OD) of the baseplate of the pedestal. The outer heater surrounds the inner heater. A diameter of an innermost turn of the outer heater is greater than or equal to the diameter of the substrate. Most of the outer heater lies in an outermost 15-20% radial width of the baseplate of the pedestal.

[0044] The inner and outer heaters are independently controlled. The inner heater maintains a temperature profile of the substrate. The outer heater compensates for the heat lost from the baseplate to the station walls through radiation. The inner heater comprises segments (e.g., arcuate, linear, curved portions, etc.) that are designed to uniformly heat the substrate as described below in detail. Using two independently controlled heater zones allows changing the amount of power supplied to the outer heater and the inner heater independently of each other. The amount of power supplied to the outer heater can be changed to compensate for varying heat losses through the edge of the pedestal due to changes in emissivity of the pedestal over time. At the same time, the amount of power supplied to the inner heater can be changed separately and independently of the power supplied to the outer heater to maintain the temperature profile of the substrate.

[0045] Accordingly, the present disclosure provides a dual zone heater system for a metallic pedestal in which geometries of heater coils in the two heater zones are optimized for achieving minimum temperature difference (delta) and hence maximum temperature uniformity across the substrate. The inner heater zone directly impacts the temperature profile of the substrate. The outer heater zone compensates for the heat loss to the station walls through radiation. Thus, the two heater zones improve the temperature uniformity across the substrate.

[0046] To independently control the two heaters, two sets of temperature sensors (e.g., thermocouples) are disposed in two separate regions of the baseplate of the

pedestal. The first set comprises a first thermocouple disposed in the center region of the baseplate of the pedestal. The first thermocouple is called an inner thermocouple. The inner thermocouple provides a temperature feedback for the inner heater zone. The inner thermocouple is removable and can be replaced upon failure.

[0047] The second set comprises two thermocouples disposed in a region of the baseplate of the pedestal that is between the inner heater zone and the outer heater zone. The two thermocouples are located outside the inner zone and inside the outer zone. The two thermocouples are called outer thermocouples. The two thermocouples can be called first and second outer thermocouples. The two outer thermocouples provide a temperature feedback for the outer heater zone. The two outer thermocouples are embedded in the baseplate of the pedestal. The second thermocouple of the two outer thermocouples provides redundancy if the first thermocouple of the two outer thermocouples fails. These and other features of the present disclosure are described below in detail.

[0048] The present disclosure is organized as follows. An example of a substrate processing system in which a metallic pedestal comprises a dual zone heater system of the present disclosure is shown and described with reference to FIG. 1. The geometries of the two heaters are shown and described in detail with reference to FIGS. 2-6C. Examples of embedding the two heaters in the metallic pedestal are shown and described with reference to FIGS. 7A and 7B. A system and method for independently controlling the power supplied to the two heaters are shown and described with reference to FIGS. 8A and 8B.

EXAMPLE OF SUBSTRATE PROCESSING SYSTEM

[0049] FIG. 1 shows an example of a substrate processing system 100. The substrate processing system 100 comprises a station 112 in which substrates are processed. While only one station 112 is shown as an example, the substrate processing system 100 may comprise a plurality of stations 112. Each station 112 may use a metallic pedestal with a dual zone heater system of the present disclosure. Different processes such as atomic layer deposition (ALD), plasma enhanced ALD (PEALD), thermal ALD (T-ALD), chemical vapor deposition (CVD), plasma enhanced CVD (PECVD), and so on may be performed on the substrate in different stations.

[0050] The station 112 comprises a pedestal (also called a substrate support) 114 and a showerhead 116. The pedestal 114 is made of a metallic material such as an alloy of

aluminum. The pedestal 114 comprises a base portion (also called a baseplate) 118 and a stem portion (also called a stem) 120. The baseplate 118 and the stem 120 are cylindrical. The stem 120 has a smaller diameter than the baseplate 118. The stem 120 is coupled to a center portion of the baseplate 118. The stem 120 extends from base portion 118 and is coupled to the bottom of the station 112. During processing, a substrate 124 is arranged on a top surface of the baseplate 118 of the pedestal 114.

[0051] The baseplate 118 comprises a dual heater system. The dual heater system is explained below in detail with reference to FIGS. 2-7B. Briefly, the dual heater system comprises an inner heater 162-1 and an outer heater 162-2. The inner and outer heaters 162-1, 162-2 heat the base portion 118 of the pedestal 114, which in turn heats the substrate 124.

[0052] The dual heater system further comprises an inner temperature sensor 164-1 and two identical outer temperature sensors 164-2, 164-3 disposed in the baseplate 118 of the pedestal 114. The inner temperature sensor 164-1 is arranged at the center of the baseplate 118. The two outer temperature sensors 164-2, 164-3 are embedded in the baseplate 118 between the inner and outer heaters 162-1, 162-2. The two outer temperature sensors 164-2, 164-3 are identical for redundancy as explained below.

[0053] The temperature sensors 164-1, 164-2, 164-3 sense temperatures of different regions of the pedestal 114 and provide feedback for controlling the inner and outer heaters 162-1, 162-2. The connections of power supplies to the inner and outer heaters 162-1, 162-2 and the connections to the temperature sensors 164-1, 164-2, 164-3 are routed through the stem 120. The connections to the two outer temperature sensors 164-2, 164-3 are separate as shown by "/" on the connecting line.

[0054] The pedestal 114 may utilize any or no clamping scheme to hold the substrate 124 on the top surface of the baseplate 118 of the pedestal 114. For example, the substrate 124 may simply rest on the top surface of the baseplate 118 of the pedestal 114 without employing any clamping scheme to clamp the substrate 124 to the pedestal 114. In some examples, the substrate 124 can be clamped to the top surface of the baseplate 118 of the pedestal 114 using a clamping mechanism such as vacuum clamping.

[0055] Alternatively, the pedestal 114 can use other types of clamping mechanism. Examples of other types of clamping mechanisms include mechanical clamping, mesas (small miniature contact areas or MCAs) disposed on the top surface of the baseplate

118 of the pedestal 114, and so on. In some processes (e.g., ALD), regardless of the clamping scheme used, the pedestal 114 with the substate 124 can be moved by an actuator 121 close to the bottom of the showerhead 116. The pedestal 114 also comprises a plurality (e.g., 3) lift pins used to lift and lower the substrate 124. The lift pins pass through bores (holes, shown in FIGS. 2-7B) in the baseplate 118 of the pedestal 114.

[0056] The showerhead 116 comprises a base portion (also called a baseplate) 126 and a stem portion (or stem) 128. The baseplate 126 of the showerhead 116 is generally cylindrical. The baseplate 126 of the showerhead 116 is greater than or equal to a diameter of the substrate 124. The stem 128 of the showerhead 116 is also generally cylindrical. The stem 128 of the showerhead 116 is of a smaller diameter than the baseplate 126 of the showerhead 116. The stem 128 of the showerhead 116 extends from the baseplate 126 of the showerhead 116. The stem 128 of the showerhead 116 is attached to a top plate of the station 112. While the showerhead 116 is shown as a chandelier style showerhead comprising the stem 128 that is attached to the top plate of the station 112, the showerhead 116 can be of any other type (e.g., flush-mounted to the top plate of the station 112).

[0057] The stem 128 of the showerhead 116 receives various gases (e.g., process gases, vaporized precursors, purge gases, cleaning gases, etc.) from a gas delivery system 150 via a manifold 152. The baseplate 126 of the showerhead 116 comprises a faceplate comprising through holes or slots (not shown) through which the gases are introduced into the station 112. While not shown, the baseplate 126 of the showerhead 116 may also comprise a heater to heat the gases, gas mixtures, and/or the vaporized precursors being introduced into the station 112 through the showerhead 116. Additionally, the baseplate 126 of the showerhead 116 may also comprise a temperature sensor 168 to sense the temperature of the showerhead 116.

[0058] The substrate processing system 100 comprises the gas delivery system 150. The gas delivery system 150 comprises gas sources 154, valves 156, and mass flow controllers (MFCs) 158. The gas sources 154 supply various gases such as process gases, inert gases (also called purge gases, edge gases, carrier gases), cleaning gases, etc. The valves 156 are connected to the gas sources 154 and the MFCs 158. The valves 156 can be controlled to supply the gases from the gas sources 154 to the

MFCs 158. The MFCs 158 regulate the flow of the gases to the manifold 152. The gases are supplied through the manifold 152 to the showerhead 116.

[0059] Additionally, in some applications (e.g., CVD), the substrate processing system 100 comprises another delivery system configured to deliver vaporized precursors via respective valves, which are collectively shown as vaporized precursors and valves 151. The vaporized precursors and valves 151 deliver vaporized precursors to the manifold 152. The manifold 152 supplies the gases or gas mixtures from the gas delivery system 150 and/or the vaporized precursors from the vaporized precursors and valves 151 to the showerhead 116. Thus, the gas delivery system 150 and the vaporized precursors and valves 151 can supply different chemistries to the showerhead 116.

[0060] The substrate processing system 100 further comprises a radio frequency (RF) power supply 160. In some processes, when plasma is used, the RF power supply 160 supplies RF power to the showerhead 116 during processing of the substrate 124 and during cleaning of the station 112 with the pedestal 114 being grounded or floating. While not shown, in some applications, the RF power supply 160 supplies RF power to the pedestal 114 during processing of the substrate 124 and during cleaning of the station 112 with the showerhead 116 being grounded or floating. The RF power excites the gases (e.g., process gases, vaporized precursors, cleaning gases, etc.) introduced into the station 112 through the showerhead 116 to generate plasma between the showerhead 116 and the pedestal 114. The plasma can be used to process the substrate 124 and to clean various components within the station 112 (e.g., the pedestal 114, sidewalls of the station 112, and so on).

[0061] The substrate processing system 100 further comprises a vacuum pump 172 and valves 170. When vacuum clamping is used to clamp the substrate 124 to the pedestal 114, the vacuum pump 172 creates vacuum on the top surface of the pedestal 114. The vacuum pump 172 also evacuates gases and reactants from the station 112. The vacuum pump 172 also maintains pressure (e.g., vacuum) in the station 112 during processing of the substrate 124.

[0062] The substrate processing system 110 further comprises a controller 180. The controller 180 controls the valves 156 and 170, the MFCs 158, the heaters in the pedestal 114 and the showerhead 116, the actuator 121, the RF power supply 160, and the vacuum pump 172. The controller 180 monitors the temperatures of the pedestal

114 and the showerhead 116 using the temperature sensors 164-1, 162-2, 164-3 in the pedestal 114 and the temperature sensor 168 in the showerhead 116. The controller 180 controls the temperatures of the pedestal 114 and the showerhead 116 by controlling the heaters in the pedestal 114 and the showerhead 116.

[0063] Additionally, while not shown, the substrate processing system 100 may also comprise a cooling system that supplies a coolant to cooling channels in the pedestal 114 and the showerhead 116. The controller 180 controls the supply of the coolant to the cooling channels in the pedestal 114 and the showerhead 116 to control the temperatures of the pedestal 114 and the showerhead 116.

EXAMPLE OF METALLIC PEDESTAL WITH TWO HEATERS

[0064] FIG. 2 shows a transverse section of the baseplate 118 of the pedestal 114 shown in FIG. 1. The transverse section shows a top view of the inner and outer heaters 162-1, 162-2 embedded in the baseplate 118 of the pedestal 114. The inner and outer heaters 162-1, 162-2 are coplanar. The inner and outer heaters 162-1, 162-2 lie in the same horizontal plane in the baseplate 118. The plane in which the inner and outer heaters 162-1, 162-2 lie is parallel to a plane of the baseplate 118. The plane in which the inner and outer heaters 162-1, 162-2 lie is also parallel to a plane in which the substrate 124 lies on the baseplate 118.

[0065] In one example, the inner and outer heaters 162-1, 162-2 may be arranged slightly vertically offset from each other in the baseplate 118. In this example, the inner and outer heaters 162-1, 162-2 may lie in two different planes that are parallel to each other and that are also parallel to the planes of the baseplate 118 and the substrate 124. Regardless of the arrangement of the inner and outer heaters 162-1, 162-2, the geometries of the inner and outer heaters 162-1, 162-2 are as described below.

[0066] The design (i.e., geometry) of the inner and outer heaters 162-1, 162-2 is symmetrical around only one diameter D1 of the baseplate 118 as described below. The right and left halves of the inner and outer heaters 162-1, 162-2 are mirror images of each other around only one diameter D1 of the baseplate 118. The design (i.e., geometry) of the inner and outer heaters 162-1, 162-2 is described below in detail with refence to subsequent figures. The locations of the temperature sensors 164-1, 164-2, 164-3 relative to the inner and outer heaters 162-1, 162-2 are also described below in detail with refence to subsequent figures.

[0067] FIG. 3 shows inner and outer zones 200-1, 200-2 of the baseplate 118 in which the inner and outer heaters 162-1, 162-2 are embedded. The inner and outer zones 200-1, 200-2 are shown by separate shaded areas for illustrative purposes. The boundary between the inner and outer zones 200-1, 200-2 is schematically shown. The inner and outer zones 200-1, 200-2 are not thermally isolated from each other. The inner zone 200-1 is circular. The inner zone 200-1 extends from a center of the baseplate 118 to a first radial distance r1. For example, the radial distance r1 is about 2/3rd the radius R of the baseplate 118. For example, r1 is 60-80% of R. The inner heater 162-1 is embedded in the inner zone 200-1 of the baseplate 118. The inner heater 162-1 is fully confined, enclosed, and contained within the inner zone 200-1 of the baseplate 118. The inner heater 162-1 is fully confined, enclosed, and contained within a circle of radius r1. The inner heater 162-1 has a complex geometry as described below in detail with reference to subsequent figures.

[0068] The outer zone 200-2 extends from a second radial distance r2 from the center of the baseplate 118 to the OD of the baseplate 118. r2 > r1. The outer zone 200-2 is annular. An inner diameter (ID) of the outer zone 200-2 is 2*r2. An OD of the outer zone 200-2 is the same as the OD of the baseplate 118. The outer zone 200-2 surrounds the inner zone 200-1. The inner and outer zones 200-1, 200-2 are concentric. The outer heater 162-2 is partially embedded in the outer zone 202-2 of the baseplate 118 and partially embedded in the inner zone 200-1 of the baseplate 118. The outer heater 162-2 is generally circular. A portion of the outer heater 162-2 extends radially through the inner zone 200-1 towards the center of the baseplate 118 to mate with power supply connections routed through the stem 120 of the pedestal 114. The outer heater 162-2 surrounds the inner heater 162-1. The geometry of the outer heater 162-2 is described below in detail with reference to subsequent figures.

[0069] The inner temperature sensor 164-1 is positioned at the center of the baseplate 118 of the pedestal 114. The inner temperature sensor 164-1 is removable. The inner temperature sensor 164-1 provides feedback to the controller 180 about the temperature in the inner zone 200-1. The outer temperatures sensors 164-2, 164-3 are embedded in a region between the inner zone 200-1 and the outer zone 200-2. The outer temperatures sensors 164-2, 164-3 lie outside the inner zone 200-1 and inside the outer zone 200-2. The outer temperatures sensors 164-2, 164-3 are arranged close together since only one of the two outer temperatures sensors 164-2, 164-3 is used for providing temperature feedback about the outer zone 200-2 to the controller 180.

[0070] In one example, the outer zone 200-2 can comprise the entire region of the baseplate 118 between r1 and the OD of the baseplate 118. In this example, the outer temperatures sensors 164-2, 164-3 lie in the outer zone 200-2. The ID of the outer zone 200-2 is 2*r2 = 2*r1. The OD of the outer zone 200-2 is the OD of the baseplate 118. Regardless of whether the ID of the outer zone 200-2 is greater than or equal to 2*r1, the outer zone 200-2 surrounds the inner zone 200-1, and the geometries of the inner and outer heaters 162-1, 162-2 remain the same as described herein.

[0071] The controller 180 shown in FIG. 1 controls the inner and outer heaters 162-1, 162-2 independently of each other as follows. The controller 180 controls the power supplied to the inner heater 162-1 based on the feedback received from the inner temperature sensor 164-1 about the temperature of the inner zone 200-1. The controller 180 controls the power supplied to the outer heater 162-2 based on the feedback received from any one of the two outer temperature sensors 164-2, 164-3 about the temperature of the outer zone 200-2. If one of the two outer temperature sensors 164-2, 164-3 fails, the controller 180 controls the power supplied to the outer heater 162-2 based on the feedback received from the other one of the two outer temperature sensors 164-2, 164-3.

[0072] The controller 180 supplies a first power through a first set of power supply connections routed through the stem 120 to the inner heater 162-1 to maintain a temperature profile of the substrate 124 for a process being performed on the substrate 124. The controller 180 supplies a second power through a second set of power supply connections routed through the stem 120 to the outer heater 162-2 to compensate for heat lost through the outer edges or periphery of the baseplate 118 of the pedestal 114 to the stations walls through radiation. The controller 180 can vary the second power supplied to the outer heater 162-2 independently of the first power supplied to the inner heater 162-1.

[0073] FIG. 4 shows a layout of the substrate 124 relative to the inner and outer heaters 162-1, 162-2 when the substrate 124 is placed on the baseplate 118 of the pedestal 114 of FIG. 2. When r2 > r1, a diameter of the substrate 124 is greater than the diameter 2*r1 of the inner zone 200-1. The diameter of the substrate 124 is less than or equal to the ID 2*r2 of the outer zone 200-2. The inner zone 200-1 and the inner heater 162-1 are fully covered by the substrate 124. The outer zone 200-2 lies outside the diameter of the substrate 124.

[0074] In the example where r2 = r1, the diameter of the substrate 124 is equal to the diameter 2*r1 of the inner zone 200-1. The diameter of the substrate 124 is equal to the ID 2*r2 of the outer zone 200-2. The inner zone 200-1 and the inner heater 162-1 are fully covered by the substrate 124. The outer zone 200-2 lies outside the diameter of the substrate 124.

[0075] FIG. 5 shows a region of the baseplate 118 in contact with the stem 120 of the pedestal 114. The region of the baseplate 118 in contact with the stem 120 of the pedestal 114 is shown by a dotted circle of radius r3. r3 < r1. The stem 120 sinks heat from the baseplate 118, which can cause cold spots in the regions of the baseplate 118 shown by the dotted circle of radius r3. As described below in detail, various portions of the inner heater 162-1 are present in the circle of radius r3 (i.e., in the region of the baseplate 118 in contact with the stem 120 of the pedestal 114). Due to the portions of the inner heater 162-1 present in the region of the baseplate 118 shown by the circle of radius r3, the stem 120 does not cause cold spots in the region of the baseplate 118 shown by the circle of radius r3. Consequently, the cold spots in the corresponding region of the substrate 124 are also minimized or eliminated.

[0076] Additionally, the baseplate 118 comprises lift pin holes 190-1, 190-2, 190-3 (collectively called the lift pin holes 190). Portions of the inner heater 162-1 are routed around the lift pin holes 190as shown. The proximity of the portions of the inner heater 162-1 to the lift pin holes 190 minimizes or eliminates formation of cold spots on the substrate 124 due to the lift pin holes 190. The proximity of the portions of the inner heater 162-1 to the lift pin holes 190 minimizes or eliminates formation of cold spots in regions of the substrate 124 that lies directly above the lift pin holes 190.

GEOMETRIES OF INNER AND OUTER HEATERS

[0077] The geometries of the inner and outer heaters 162-1, 162-2 are now described in detail with reference to FIGS. 6A-6C. FIGS. 6A-6C are the same as FIGS. 2 and 3 except that the inner and outer zones are not shaded in FIG. 6A and are omitted in FIGS. 6B and 6C. Some of the reference numerals used to identify elements in FIGS. 2 and 3 are omitted in FIGS. 6A-6C to reduce crowding. Further, some of the reference numerals used to identify elements in FIGS. 2, 3, and 6A are omitted in FIGS. 6B and 6C to reduce crowding. The indications of the substrate 124 and the stem 120 shown in FIGS. 4 and 5 are also omitted in FIGS. 6A-6C to reduce crowding.

[0078] While the geometries of the inner and outer heaters 162-1, 162-2 are described mainly with reference to FIG. 6A, FIGS. 6B and 6C show additional geometric references (e.g., angles) used to describe the geometries of the inner and outer heaters 162-1, 162-2. In the description of the inner and outer heaters 162-1, 162-2, the turns are curved portions of the inner and outer heaters 162-1, 162-2 that change the direction of layout of the inner and outer heaters 162-1, 162-2.

[0079] In FIG. 6A, the baseplate 118 of the pedestal 114 is divided into four quadrants. The four quadrants are labeled as Q1, Q2, Q3, and Q4 similar to the quadrants used in a Cartesian plane. In FIG. 6B, a square 210 encloses the baseplate 118 of the pedestal 114. Diagonals of the square 210 bisect the four quadrants into two 45-degree portions (halves). In FIG. 6C, the baseplate 118 of the pedestal 114 is analogized to a dial of a circular analog clock with the hour markers 1-12. Diametric lines are drawn to show twelve 30-degree portions of the baseplate 118 of the pedestal 114. The diametric lines divide the four quadrants into three 30-degree portions.

[0080] The baseplate 118 of the pedestal 114 is divided into the four quadrants using the diameter D1 around which the inner and outer heaters 162-1, 162-2 are symmetrical and the diameter D2 that is perpendicular to the diameter D1. The diameter D1 is the only diameter of the base plate 118 that is perpendicular to and bisects a line joining the locations of the two outer temperature sensors 164-2, 164-3. The inner temperature sensor 164-1 located at the center of the baseplate 118 lies at the intersection of the diameters D1 and D2. The two outer temperature sensors 164-2, 164-3 lie on either side of the diameter D1 in the fourth and third quadrants Q4 and Q3, respectively.

[0081] As described below in detail, the design (i.e., geometry) of the inner and outer heaters 162-1, 162-2 is symmetrical around only one diameter D1 of the baseplate 118 of the pedestal 114. Right and left halves of the inner and outer heaters 162-1, 162-2 are mirror images of each other around only one diameter D1 of the baseplate 118 of the pedestal 114. The right halves in the quadrants Q1 and Q4 and the left halves in the quadrants Q2 and Q3 of the inner and outer heaters 162-1, 162-2 are mirror images of each other.

[0082] In FIG. 6B, the diameters D1 and D2 bisect opposite sides of the square 210 that surrounds the baseplate 118 of the pedestal. In FIG. 6C, the diameter D1 connects the hour markers 12 and 6, and the diameter D2 connects the hour markers 9 and 3. In

FIG. 6C, the first quadrant Q1 lies between the hour markers 12 and 3. The fourth quadrant Q4 lies between the hour markers 3 and 6. The third quadrant Q3 lies between the hour markers 6 and 9. The second quadrant Q2 lies between the hour markers 9 and 12.

INNER HEATER

[0083] The inner heater 162-1 comprises many portions. For example, the inner heater 162-1 comprises an arcuate portion, multiple linear portions, multiple curved portions, and multiple turns, which are described below in detail. The arcuate portion lies in quadrants Q1 and Q2, and two turns lie in each of the quadrants Q1 through Q4 as described below in detail. The multiple portions of the inner heater 162-1 have geometries described below that are designed to uniformly heat the inner zone 200-1 of the baseplate 118 without forming hot spots or cold spots in the baseplate 118. Accordingly, the substrate 124, which lies mostly over the inner zone 200-1, is also uniformly heated without hot spots or cold spots as described below in detail.

[0084] The inner heater 162-1 comprises first and second terminals 250 and 252 (shown in FIG. 2). The controller 180 supplies power to the first and second terminals 250 and 252 via power supply lines routed through the stem 120 of the pedestal 114. The first and second terminals 250 and 252 lie in a center portion of the baseplate 118. The first and second terminals 250 and 252 lie on right and left sides of the diameter D in quadrants Q1 and Q2, respectively.

[0085] A first portion 254 of the inner heater 162-1 extends linearly from the first terminal 250. The first portion 254 extends away from the center portion of the baseplate 118 and extends outwards into the inner zone 200-1. The first portion 254 extends parallel to the diameter D1 towards the 12 O'clock position (see FIG. 6C). The first portion 254 is linear and lies in quadrant Q1.

[0086] At the end of the first portion 254, the inner heater 162-1 comprises a first turn 256. The first turn 256 turns the inner heater 162-1 clockwise. The first turn 256 turns the inner heater 162-1 away from the center portion of the baseplate 118, away from the diameter D1, and towards the diameter D2. The first turn 256 turns the inner heater 162-1 inwards into the inner zone 200-1. The first portion 254 and the first turn 256 lie within one half of the quadrant Q1 (i.e., within 45 degrees from the diameter D1; see FIG. 6B). The first portion 254 and the first turn 256 lie between 12 O's clock and 1 O'clock positions (see FIG. 6C).

[0087] At the end of the first turn 256, a second portion 258 of the inner heater 162-1 that extends through the quadrant Q1 and into the quadrant Q4. The second portion 258 is curved and comprises first and second sub-portions. The first sub-portion of the second portion 258 extends from the end of the first turn 256. The first sub-portion of the second portion 258 curves radially inwards into the quadrant Q1 towards the first portion 254. The first sub-portion of the second portion 258 curves towards the diameters D1 and D2 and towards the center portion of the baseplate 118 until the first sub-portion intersects the diameter D2. The first portion 254, the first turn 256, and the first sub-portion of the second portion 258 lie in quadrant Q1. The first portion 254, the first turn 256, and most of the first sub-portion of the second portion 258 lie within one half of the quadrant Q1 (i.e., within 45 degrees from the diameter D1; see FIG. 6B). The first portion 254, the first turn 256, and most of the first sub-portion of the second portion 258 lie between 12 O'clock and 2 O'clock positions (see FIG. 6C).

[0088] The second sub-portion of the second portion 258 extends from the point of intersection at which the first sub-portion of the second portion 258 intersects the diameter D2 (i.e., from the first sub-portion of the second portion 258). The second sub-portion of the second portion 258 extends the inner heater 162-1 into the quadrant Q4. The second sub-portion of the second portion 258 curves radially outwards into the quadrant Q4. The second sub-portion of the second portion 258 extends away from the center portion of the baseplate 118 and away from the first and second diameters into the quadrant Q4. The second sub-portion of the second portion 258 lies on the opposite side of the diameter D2 relative to the first sub-portion of the second portion 258.

[0089] At the end of the second portion 258, the inner heater 162-1 comprises a second turn 260. The second turn 260 turns counter-clockwise. The second turn 260 turns the inner heater 162-1 away from the center portion of the baseplate 118. The second turn 260 turns away from the diameter D1 and towards the diameter D2. The second turn 260 turns the inner heater 162-1 outwards into the inner zone 200-1. The second turn 260 lies in the quadrant Q4. Most of the second turn 260 lies within one half of the quadrant Q4 (i.e., within 45 degrees from the diameter D1; see FIG. 6B).

[0090] At the end of the second turn 260, a third portion 262 of the inner heater 162-1 extends linearly inwards towards the center portion of the baseplate 118, towards the diameters D1 and D2, and towards the intersection of the second portion 258 with the diameter D2. The third portion 262 extends at nearly 45 degrees relative to the

diameters D1 and D2 (see FIG. 6B). Most of the third portion 262 lies within one half of the quadrant Q4 (i.e., within 45 degrees from the diameter D2; see FIG. 6B). The second sub-portion of the second portion 258, the second turn 260, and the third portion 262 lie in the quadrant Q4. The second sub-portion of the second portion 258, the second turn 260, and the third portion 262 of the inner heater 162-1 lie between 6 O'clock and 4 O'clock positions (see FIG. 6C).

[0091] At the end of the third portion 262, the inner heater 162-1 comprises a third turn 264. The third turn 264 turns the inner heater 162-1 clockwise into the quadrant Q4. The third turn 264 turns away from the center portion of the baseplate 118. The third turn 264 turns away from the diameter D1 and towards the diameter D2. The third turn 264 turns the inner heater 162-1 outwards into the inner zone 200-1. The third turn 264 intersects the diameter D2 at both ends of the third turn 264. Most of the third turn 264 lies in the quadrant Q1. Most of the third turn 264 lies within one half of the quadrant Q1 (i.e., within 45 degrees from the diameter D2; see FIG. 6B). Most of the third turn 264 lies in the quadrant Q1. Most of the third turn 264 lies between 2 O'clock and 3 O'clock positions (see FIG. 6C).

[0092] At the end of the third turn 264, the inner heater 162-1 comprises a fourth turn 266. The fourth turn 266 turns the inner heater 162-1 counter-clockwise. The fourth turn 266 turns away from the center portion of the baseplate 118. The fourth turn 266 turns away from the diameter D1 and towards the diameter D2. The fourth turn 266 turns the inner heater 162-1 outwards into the inner zone 200-1. The fourth turn 266 lies in the quadrant Q4. The fourth turn 266 lies within one half of the quadrant Q4 (i.e., within 45 degrees from the diameter D2; see FIG. 6B). The fourth turn 266 lies between 3 O'clock and 4 O'clock positions (see FIG. 6C).

[0093] At the end of the fourth turn 266, the inner heater 162-1 comprises an arcuate portion 268. The arcuate portion 268 is semicircular. The arcuate portion 268 extends counter-clockwise along the circle of radius r1, which bounds the inner zone 200-1. The arcuate portion 268 extends away from the diameter D2 into the quadrant Q1, intersects the diameter D1, and extends towards the diameter D2 in the quadrant Q2. The arcuate portion 268 intersects the diameter D2 at both ends of the arcuate portion 268. The arcuate portion 268 extends through the quadrants Q1 and Q2. Most of the arcuate portion 268 lies in the quadrants Q1 and Q2. Only end portions of the arcuate

portion 268 lie in the quadrants Q4 and Q3. Most of the arcuate portion 268 lies between 3 O'clock and 9 O'clock positions (see FIG. 6C).

[0094] At the end of the arcuate portion 268, the inner heater 162-1 comprises a fifth turn 270. The fifth turn 270 turns the inner heater 162-1 clockwise. The fifth turn 270 turns towards the center portion of the baseplate 118. The fifth turn 270 turns towards the diameters D1 and D2. The fifth turn 270 turns the inner heater 162-1 inwards into the inner zone 200-1. The fifth turn 270 lies in the quadrant Q3. The fifth turn 270 lies within one half of the quadrant Q3 (i.e., within 45 degrees from the diameter D2; see FIG. 6B). The fifth turn 270 lies between 9 O'clock and 8 O'clock positions (see FIG. 6C).

[0095] At the end of the fifth turn 270, the inner heater 162-1 comprises a sixth turn 272. The sixth turn 272 turns the inner heater 162-1 counter-clockwise. The sixth turn 272 turns towards the center portion of the baseplate 118. The sixth turn 272 turns towards the diameters D1 and diameter D2. The sixth turn 272 turns the inner heater 162-1 inwards into the inner zone 200-1. The sixth turn 272 intersects the diameter D2 at both ends of the sixth turn 272. Most of the sixth turn 272 lies in the quadrant Q2. Most of the sixth turn 272 lies within one half of the quadrant Q2 (i.e., within 45 degrees from the diameter D2; see FIG. 6B). Most of the sixth turn 272 lies between 9 O'clock and 10 O'clock positions (see FIG. 6C).

[0096] At the end of the sixth turn 272, a fourth portion 274 of the inner heater 162-1 extends linearly outwards away from the center portion of the baseplate 118 and away from the diameters D1 and D2. The fourth portion 274 extends outwards into the quadrant Q3. The fourth portion 274 extends at nearly 45 degrees relative to the diameters D1 and D2 (see FIG. 6B). Most of the fourth portion 274 lies within one half of the quadrant Q3 (i.e., within 45 degrees from the diameter D2; see FIG. 6B).

[0097] At the end of the fourth portion 274, the inner heater 162-1 comprises a seventh turn 276. The seventh turn 276 turns the inner heater 162-1 counter-clockwise. The seventh turn 276 turns towards the center portion of the baseplate 118. The seventh turn 276 turns towards the diameters D1 and D2. The seventh turn 276 turns the inner heater 162-1 inwards into the inner zone 200-1. The seventh turn 276 lies in the quadrant Q3. Most of the seventh turn 276 lies within one half of the quadrant Q3 (i.e., within 45 degrees from the diameter D1; see FIG. 6B).

[0098] At the end of the seventh turn 276, a fifth portion 278 of the inner heater 162-1 extends through the quadrant Q3 into the quadrant Q2. The fifth portion 278 is curved and comprises first and second sub-portions. The first sub-portion of the fifth portion 278 extends from the end of the seventh turn 276. The first sub-portion of the fifth portion 278 curves radially inwards towards the center portion of the baseplate 118, towards the diameters D1 and D2, that interests the diameter D2. The first sub-portion of the fifth portion 278 extends the inner heater 162-1 into the quadrant Q2. The fifth turn 270, the fourth portion 274, the seventh turn 276, and the first sub-portion of the fifth portion 278 lie in the quadrant Q3. Most of the seventh turn 276 and the first sub-portion of the fifth portion 278 lie within one half of the quadrant Q3 (i.e., within 45 degrees from the diameter D1; see FIG. 6B). The fourth portion 274, the seventh turn 276, and the first sub-portion of the fifth portion 278 lie between 6 O'clock and 8 O'clock positions (see FIG. 6C).

[0099] The second sub-portion of the fifth portion 278 extends from the point of intersection of the first sub-portion of the fifth portion 278 with the diameter D2 (i.e., from the first sub-portion of the fifth portion 278). The second sub-portion of the fifth portion 278 extends the inner heater 162-1 into the quadrant Q2. The second sub-portion of the fifth portion 278 curves outwards and away from the center portion of the baseplate 118, and away from the diameters D1 and D2 into the quadrant Q2.

[0100] At the end of the fifth portion 278, the inner heater 162-1 comprises an eighth turn 280. The eighth turn 280 turns the inner heater 162-1 clockwise. The eighth turn 280 turns towards the center portion of the baseplate 118. The eighth turn 280 turns towards the diameters D1 and D2. The eighth turn 280 turns the inner heater 162-1 inwards into the inner zone 200-1. The eighth turn 280 lies in the quadrant Q2. The eighth turn 280 lies within one half of the quadrant Q2 (i.e., within 45 degrees from the diameter D1; see FIG. 6B). The eighth turn 280 lies between 11 O'clock and 12 O'clock positions (see FIG. 6C).

[0101] At the end of the eighth turn 280, a sixth portion 282 of the inner heater 162-1 extends linearly to the second terminal 252. The sixth portion 282 extends towards the center portion of the baseplate 118 and extends parallel to the diameter D1 towards the second terminal 252. The sixth portion 282 is linear and lies in the quadrant Q2. The sixth portion 282 and the eighth turn 280 lie within one half of the quadrant Q2 (i.e., within 45 degrees from the diameter D1; see FIG. 6B). The sixth portion 282 and the

eighth turn 280 lie between 11 O's clock and 12 O'clock positions (see FIG. 6C). The sixth turn 272, the second sub-portion of the fifth portion 278, the eighth turn 280, and the sixth portion 282 lie between 9 O'clock and 12 O'clock positions (see FIG. 6C).

[0102] Accordingly, in the inner heater 162-1, elements 254, 256, 264, and portions of elements 258 and 268 lie in the quadrant Q1. Elements 282, 280, 272, and portions of elements 26 and 278 lie in the quadrant Q2. Elements 270, 274, 276, and portions of elements 268, 272, and 278 lie in the quadrant Q3. Elements 260, 262, 266, and portions of elements 268, 264, and 258 lie in the quadrant Q4.

[0103] Thus, the inner heater 162-1 comprises multiple portions that are spread throughout the inner zone 200-1 of the baseplate 118 of the pedestal 114. The multiple portions of the inner heater 162-1 turn the inner heater 162-1 clockwise and counter-clockwise multiple times to cover most of the area on the inner zone 200-1. The multiple portions of the inner heater 162-1 are positioned neither close together nor far apart from each other to uniformly heat the inner zone 200-1 of the baseplate 118 and to avoid forming hot spots and cold spots in the baseplate 118. The multiple portions of the inner heater 162-1 have geometries designed to uniformly heat the inner zone 200-1 of the baseplate 118 of the pedestal 114. As described above, most of the substrate 124 lies above the inner zone 200-1. Due to the uniform heating provided by the inner heater 162-1 and portions of the outer heater 162-2 that extend into the inner zone 200-1 described below, most of the substrate 124 is uniformly heated without forming hot spots and cold spots on the substrate 124.

[0104] Further, as described below, the portions of the inner heater 162-1 that lie near the center of the baseplate 118 of the pedestal also cover the region of the baseplate 118 where the stem 120 of the pedestal 114 is connected to the baseplate 118 of the pedestal 114. As seen from FIGS. 5 and 6A, portions of elements 254, 258, 264, 278, 272, 282 lie within the circle of radius r3, which represents the region of the baseplate 118 where the stem 120 contacts the baseplate. The portions of elements 254, 258, 264, 278, 272, 282 heat the region of the baseplate 118 within the circle of radius r3 from where the stem 120 sink heat from the baseplate. Accordingly, cold spots that can be otherwise caused by the stem 120 in the region of the baseplate 118 within the circle of radius r3 are minimized or eliminated by the geometries of these portions of the inner heater 162-1 that lie in the region of the baseplate 118 within the circle of radius r3. In

addition, the geometry of the outer heater 162-2 described below also uniformly heats the outer edges or peripheral portions of the substrate 124.

OUTER HEATER

[0105] In FIGS. 6A-6C, the outer heater 162-2 also comprises many portions. For example, the outer heater 162-2 comprises multiple arcuate portions, a circular portion, and multiple linear portions and turns, which are described below in detail. The arcuate and circular portions lie in all the quadrants Q1 through Q4, one turn lies in each of the quadrants Q1 through Q4, and linear portions lie in quadrants Q3 and Q4 as described below in detail. The multiple portions of the outer heater 162-2 have geometries described below that are designed to uniformly heat the outer zone 200-2 of the baseplate 118 of the pedestal 114. The linear portions of the outer heater 162-2 are also arranged relative to some of the portions of the inner heater 162-1 to uniformly heat portions of the substrate 124 as described below in detail.

[0106] The outer heater 162-2 comprises first and second terminals 300 and 302 (shown in FIG. 2). The controller 180 supplies power to the first and second terminals 300 and 302 via power supply lines routed through the stem 120 of the pedestal 114. The first and second terminals 300 and 302 lie in the center portion of the baseplate 118 opposite to the first and second terminals 250 and 252 of the inner heater 162-1. The first and second terminals 300 and 302 lie in quadrants Q4 and Q3, respectively. The inner temperature sensor 164-1 is surrounded by the terminals 250, 252, 300, 302.

[0107] A first portion 304 of the outer heater 162-2 extends linearly from the first terminal 300. The first portion 304 extends away from the center portion of the baseplate 118 and from the diameter D2. The first portion 304 extends through the inner zone 200-1 towards the periphery of the inner zone 200-1. The first portion 304 extends parallel to the diameter D1. The first portion 304 is linear. The first portion 304 lies in the inner zone 200-1. The first portion 304 lies in the quadrant Q4. The first portion 304 extends towards the 6 O'clock position (see FIG. 6B). The first portion 304 lies between 6 O'clock and 5 O'clock positions (see FIG. 6C).

[0108] At the end of the first portion 304, a second portion 306 of the outer heater 162-2 extends outwards, at an acute angle away from the diameter D1, and into the outer zone 200-2. The second portion 306 is also linear. The second portion 306 lies partially in the inner zone 200-1 and also partially in the outer zone 200-2. The second portion 306 lies in the quadrant Q4. The second portion 306 lies within a half portion of the

quadrant Q4 that is adjacent to the diameter D1 (see FIG. 6B). The second portion 306 extends towards the 5 O'clock position (see FIG. 6B). The second portion 306 lies between 6 O'clock and 5 O'clock positions (see FIG. 6C).

[0109] At the end of the second portion 306, the outer heater 162-2 comprises a first turn 308. The first turn 308 turns the outer heater 162-2 counter-clockwise. The first turn 308 turns the outer heater 162-2 away from the diameter D1 and turns the outer heater 162-2 towards the OD of the baseplate 118 of the pedestal 114. The first turn 308 lies in the outer zone 200-2. The first portion 304, the second portion 306, and the first turn 308 lie in the quadrant Q4. The first portion 304, the second portion 306, and the first turn 308 lie within a half portion of the quadrant Q4 that is adjacent to the diameter D1 (see FIG. 6B). The first portion 304, the second portion 306, and the first turn 308 lie between 6 O'clock and 5 O'clock positions (see FIG. 6C).

[0110] At the end of the first turn 308, a first arcuate portion 310 extends the outer heater 162-2 from the quadrant Q4 into the quadrant Q1. The first arcuate portion 310 extends counter-clockwise along (parallel to) the OD of the baseplate 118. The first arcuate portion 310 lies in quadrants Q4 and Q1. The first arcuate portion 310 lies in the outer zone 200-2. The first arcuate portion 310 extends up to the diameter D1 in the quadrant Q1 but does not intersect the diameter D1. The first arcuate portion 310 is semi-circular.

[0111] In the outer zone 200-2, at the end of the first arcuate portion 310, the outer heater 162-2 comprises a second turn 312 in the quadrant Q1. The second turn 312 turns the outer heater 162-2 clockwise. The second turn 312 turns the outer heater 162-2 away from the diameter D1. The second turn 312 turns the outer heater 162-2 radially outwards relative to the first arcuate portion 310. The second turn 312 lies within a half portion of the quadrant Q1 that is adjacent to the diameter D1 (see FIG. 6B). The second turn 312 lies between 12 O'clock and 1 O'clock positions (see FIG. 6C).

[0112] In the outer zone 200-2, at the end of the second turn 312, a second arcuate portion 314 extends the outer heater 162-2 clockwise from the quadrant Q1, through quadrants Q4 and Q3 intersecting the diameter D1, into the quadrant Q2. The second arcuate portion 314 lies in the outer zone 200-2. The second arcuate portion 314 lies in all four quadrants Q1 though Q4. The second arcuate portion 314 extends along (parallel to) the OD of the baseplate 118. The second arcuate portion 314 surrounds the first arcuate portion 310. The second arcuate portion 314 lies between the first

arcuate portion 310 and the OD of the baseplate 118. The end of the second arcuate portion 314 extends up to the diameter D1 in the quadrant Q2 but does not intersect the diameter D1. The second arcuate portion 314 is mostly circular.

[0113] In the outer zone 200-2, at the end of the second arcuate portion 314, the outer heater 162-2 comprises a third turn 316 in the quadrant Q2. The third turn 316 turns the outer heater 162-2 counter-clockwise. The third turn 316 turns the outer heater 162-2 away from the diameter D1. The third turn 316 turns the outer heater 162-2 radially inwards relative to the second arcuate portion 314. The third turn 316 lies within a half portion of the quadrant Q2 that is adjacent to the diameter D1 (see FIG. 6B). The third turn 316 lies between 12 O'clock and 11 O'clock positions (see FIG. 6C).

[0114] In the outer zone 200-2, at the end of the third turn 316, a third arcuate portion 318 extends the outer heater 162-2 from the quadrant Q2 into the quadrant Q3. The third arcuate portion 318 extends counter-clockwise along (parallel to) the OD of the baseplate 118. The third arcuate portion 318 lies in quadrants Q2 and Q3. The third arcuate portion 318 extends up to the diameter D1 in the quadrant Q3 but does not intersect the diameter D1. The third arcuate portion 318 is semi-circular.

[0115] In the outer zone 200-2, at the end of the third arcuate portion 318, the outer heater 162-2 comprises a fourth turn 320 in the quadrant Q3. The fourth turn 320 turns the outer heater 162-2 towards the diameter D1 and towards the center portion of the baseplate 118 of the pedestal 114. The fourth turn 320 turns the outer heater 162-2 turns the outer heater 162-2 away from the OD of the baseplate 118 of the pedestal 114. The fourth turn 320 lies in the quadrant Q3. The fourth turn 320 lies within a half portion of the quadrant Q3 that is adjacent to the diameter D1 (see FIG. 6B). The fourth turn 320 lies between 6 O'clock and 7 O'clock positions (see FIG. 6C).

[0116] At the end of the fourth turn 320, a third portion 322 of the outer heater 162-2 extends radially inwards, at an acute angle from the diameter D1, towards the diameter D1 and into the inner zone 200-1. The third portion 322 is linear. The third portion 322 lies partially in the outer zone 200-2 and also partially in the inner zone 200-1. The third portion 322 lies in the quadrant Q3. The third portion 322 lies within a half portion of the quadrant Q3 that is adjacent to the diameter D1 (see FIG. 6B). The third portion 322 lies between 6 O'clock and 7 O'clock positions (see FIG. 6C).

[0117] At the end of the third portion 322, a fourth portion 324 of the outer heater 162-2 extends linearly to the first terminal 300. The fourth portion 324 extends towards the

center portion of the baseplate 118 and towards the diameter D2. The fourth portion 324 extends parallel to the diameter D1. The fourth portion 324 is linear. The fourth portion 324 lies in the inner zone 200-1. The fourth portion 324 lies in the quarter Q3. The fourth turn 320, the third portion 322, and the fourth portion 324 of the outer heater 162-2 lie in the quadrant Q3. The fourth turn 320, the third portion 322, and the fourth portion 324 of the outer heater 162-2 lie within a half portion of the quadrant Q3 that is adjacent to the diameter D1 (see FIG. 6B). The fourth turn 320, the third portion 322, and the fourth portion 324 of the outer heater 162-2 lie between 6 O'clock and 7 O'clock positions (see FIG. 6C).

[0118] Accordingly, in the outer heater 162-2, elements 304, 306, 308, and portions of elements 310 and 314 lie in the quadrant Q4. Element 312 and portions of elements 310 and 314 lie in the quadrant Q1. Element 316 and portions of elements 314 and 318 lie in the quadrant Q2. Elements 320, 322, 326, and portions of elements 310 and 314 lie in the quadrant Q3. Elements 308, 312, 314, 316, 318 lie in the outer zone 200-2. Elements 304, 306, 322, 324 lie in the inner zone 200-1. Elements 306 and 322 lie partially in the outer zone 200-2 and partially in the inner zone 200-1. The multiple portions of the outer heater 162-2 turn the outer heater 162-2 clockwise and counter-clockwise multiple times to cover most of the area on the outer zone 200-2.

[0119] Portions of elements 254, 258, 264, 304, 324, 278, 272, 282 of the inner and outer heaters 162-1, 162-2 lie within the circle of radius r3 shown in FIG. 5. These portions minimize or eliminates cold spots otherwise caused in the baseplate 118 and in the substrate 124 by the heat drawn from the baseplate 118 by the stem 120. Additionally, elements 310, 314, 318, 308, 320, 312, 316 of the outer heater 162-2 compensate for the heat lost from the outer edges of the baseplate 118 to the station walls through radiation.

[0120] The heat losses increase as the emissivity of the pedestal 114 increases over time. The controller 180 controls the inner and outer heaters 162-1, 162-2 independently of each other. The controller 180 can control the outer heater 162-2 and increase power supplied to the outer heater 162-1 to compensate for the increased heat losses while maintaining the temperature profile of the substrate 124 by changing the power supplied to the inner heater 162-1 independently of the power supplied to the outer heater 162-2. Accordingly, the temperature profile of the substrate 124, which is determined mostly by the inner heater 162-1, can be maintained.

[0121] Elements of the inner and outer heaters 162-1, 162-2 have the above geometries and are spaced apart from each other to uniformly heat baseplate 118 and the substrate 124 without causing cold spots or hot spots. For example, elements 256 and 280 are spaced apart from each other, from element 268, and from elements 264 and 272. Elements 266 and 270 are spaced apart from elements 262, 260, 274, 276. Elements 260 and 276 are spaced apart from elements 304 and 324, and from elements 306 and 322. Element 258 and 278 are curved and spaced apart from elements 262 and 274, and from elements 304 and 324. Elements 306 and 322 are angled to not bias the outer temperature sensors 164-2, 164-3. Elements 306 and 322 are angled to not form a cold spot in regions between elements 260 and 306 and between elements 276 and 322. Elements 268, 266, 260, 276, and 270 are spaced apart from elements 310 and 318.

[0122] Elements 312 and 316 are positioned apart from each other (e.g., at an equal predetermined distance from the diameter D1) so that hot spots are not formed in the region between elements 312 and 316. Elements 308 and 320 are positioned apart from each other (e.g., at an equal predetermined distance from the diameter D1) so that hot spots are not formed in the region between elements 308 and 320. The separation between elements 308 and 320 is achieved by angling elements 306 and 322.

[0123] The diameter D1 of the baseplate 118 separates the quadrants Q1 and Q4 from the quadrants Q2 and Q3. The diameter D1 of the baseplate 118 intersects only elements 268 and 314 of the inner and outer heaters 162-1, 162-2. The diameter D1 of the baseplate 118 does not intersect any other elements or portions of the inner and outer heaters 162-1, 162-2. All other elements or portions of the inner and outer heaters 162-1, 162-2 lie on either side of the diameter D1 as described above, which makes the inner and outer heaters 162-1, 162-2 symmetric around the diameter D1. The inner and outer heaters 162-1, 162-2 are symmetric around the diameter D1 that separates the quadrants Q1 and Q4 from the quadrants Q2 and Q3. All other elements or portions of the inner and outer heaters 162-1, 162-2 lie on either side of the diameter D1 as described above, which makes the elements or portions of the inner and outer heaters 162-1, 162-2 in the quadrants Q1 and Q4 mirror images of the elements or portions of the inner and outer heaters 162-1, 162-2 in the quadrants Q2 and Q3.

[0124] FIGS. 7A and 7B show two different implementations of the inner and outer heaters 162-1, 162-2 in the baseplate 118 of the pedestal 114 of FIG. 2 according to

the present disclosure. The inner and outer heaters 162-1, 162-2 comprise heating elements (e.g., coils) that are two-terminal devices across which power is applied. The inner and outer heaters 162-1, 162-2 can comprise heating elements with a D-shaped cross-section as shown in FIG. 7A. Alternatively, the inner and outer heaters 162-1, 162-2 can comprise heating elements with a circular cross-section as shown in FIG. 7B.

[0125] In FIGS. 7A and 7B, the baseplate 118 comprises a first plate 118-1 and a second plate 118-2. The first plate 118-1 and the second plate 118-2 are made of the metallic material such as an alloy of aluminum. The inner and outer heaters 162-1, 162-2 are sandwiched between the first plate 118-1 and the second plate 118-2.

[0126] In FIG. 7A, a bottom surface of the first plate 118-1 is machined to form channels in which the D-shaped coils of the inner and outer heaters 162-1, 162-2 can be arranged. A top surface of second plate 118-2 is flat and is bonded to the bottom surface of the first plate 118-1.

[0127] In FIG. 7B, the bottom surface of the first plate 118-1 and the top surface of the second plate 118-2 are machined to form channels in which the round coils of the inner and outer heaters 162-1, 162-2 can be arranged. The top surface of second plate 118-2 is flat and is bonded to the bottom surface of the first plate 118-1.

[0128] FIG. 8A shows a system for independently controlling the power supplied to the inner and outer heaters 162-1, 162-2 according to the present disclosure. The system comprises the controller 180 shown in FIG. 1. For example, the controller 180 comprises a power supply 181 to supply power to the inner and outer heaters 162-1, 162-2 independently of each other as described above. The power supply 181 may generate and supply the first power to the inner heater 162-1 and may generate and supply the second power to the outer heater 162-2.

[0129] Alternatively, the power supply 181 may comprise a first power supply PS1 to generate and supply the first power to the inner heater 162-1. The power supply 181 may comprise a second power supply PS2 to generate and supply the second power to the outer heater 162-2. For example, the first power supply PS1 may be connected to the terminals 250, 252 of the inner heater 162-1. The second first power supply PS2 may be connected to the terminals 300, 302 of the outer heater 162-2. While the power supply 181 and the power supplies PS1, PS2 are shown internal to the controller 180, the power supply 181 and the power supplies PS1, PS2 may be external to the controller 180.

[0130] The power supply 181 (or the first power supply PS1) may control the first power supplied to the inner heater 162-1 based on the feedback received from the inner temperature sensor 164-1. The power supply 181 (or the second power supply PS2) may control the second power supplied to the outer heater 162-2 based on the feedback received from one of the outer temperature sensors 164-2, 164-3. If the temperature sensor 164-2 fails, the controller 180 uses the temperature sensor 164-3 to control the second power supplied to the outer heater 162-2. The controller 180 controls the first power and the second power supplied to the inner and outer heaters 162-1, 162-2 independently of each other as described above.

[0131] FIG. 8B shows a method 350 for independently controlling the power supplied to the inner and outer heaters 162-1, 162-2 according to the present disclosure. For example, the controller 180 may perform the method 350. At 352, the controller 180 receives a temperature setpoint for heating the substrate 124. At 352, the controller 180 supplies the first power to the inner heater 162-1 (e.g., from the power supply 181 or the power supply PS1) based on the temperature setpoint. At 354, the controller 180 controls the first power supplied to the inner heater 162-1 (i.e., the controller 180 controls the power supply 181 or the power supply PS1) based on feedback received from the inner temperature sensor 164-1.

[0132] At 358, the controller 180 supplies the second power to the outer heater 162-2 (e.g., from the power supply 181 or the power supply PS2) to compensate for heat losses from the edges of the edges of the pedestal 114 to the station walls through radiation. At 360, the controller 180 controls the second power supplied to the outer heater 162-2 (i.e., controls the power supply 181 or the power supply PS2) based on feedback received from the outer temperature sensor 164-2.

[0133] At 362, the method 350 determines if the outer temperature sensor 164-2 has failed. If the outer temperature sensor 164-2 has not failed, the method 350 returns to 352. If the outer temperature sensor 164-2 has failed, at 364, the controller 180 selects the outer temperature sensor 164-3 and controls the second power supplied to the outer heater 162-2 (i.e., controls the power supply 181 or the power supply PS2) based on feedback received from the outer temperature sensor 164-3. The method 350 returns to 352. Thus, the controller 180 180 controls the first power and the second power supplied to the inner and outer heaters 162-1, 162-2 independently of each other.

[0134] The foregoing description is merely illustrative in nature and is not intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims.

[0135] It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the examples is described above as having certain features, any one or more of those features described with respect to any one of the examples of the disclosure can be implemented in and/or combined with features of any of the other examples, even if that combination is not explicitly described. In other words, the described examples are not mutually exclusive, and permutations of one or more examples with one another remain within the scope of this disclosure.

[0136] Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including "connected," "engaged," "coupled," "adjacent," "next to," "on top of," "above," "below," and "disposed." Unless explicitly described as being "direct," when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean "at least one of A, at least one of B, and at least one of C."

[0137] In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, including a processing tool or tools, chamber or chambers, a platform or platforms for processing, and/or specific processing components (a wafer pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate.

[0138] The electronics may be referred to as the "controller," which may control various components or subparts of the system or systems. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

[0139] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, non-transitory memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software).

[0140] Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some examples, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0141] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with the system, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the "cloud" or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process.

[0142] In some examples, a remote computer (e.g., a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control.

[0143] Thus, as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

[0144] Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0145] As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

CLAIMS

What is claimed is:

1. A substrate support for processing a substrate comprising:
a baseplate;
a first heater arranged in a first portion of the baseplate; and
a second heater arranged in a second portion of the baseplate and partially arranged in the first portion of the baseplate.

2. The substrate support of claim 1 wherein:
the second heater surrounds the first heater; and
the second portion surrounds the first portion.

3. The substrate support of claim 1 wherein:
the baseplate is cylindrical;
the first portion is circular and comprises a center of the baseplate;
the second portion is annular and surrounds the first portion; and
the first portion and the second portion are concentric.

4. The substrate support of claim 1 wherein the first heater and the second heater are separately controlled.

5. The substrate support of claim 1 wherein the first heater and the second heater comprise curved and linear portions.

6. The substrate support of claim 1 wherein the first heater and the second heater comprise portions extending in clockwise and counter-clockwise directions.

7. The substrate support of claim 1 wherein the first heater and the second heater are symmetric around a diameter of the baseplate.

8. The substrate support of claim 1 wherein:

the baseplate is cylindrical and comprises four quadrants Q1, Q2, Q3, and Q4; and

the first heater and the second heater are symmetric around a diameter of the baseplate that separates Q1 and Q4 from Q2 and Q3.

9. The substrate support of claim 1 wherein:

the baseplate is cylindrical and comprises four quadrants Q1, Q2, Q3, and Q4; and

portions of the first heater and the second heater in Q1 and Q4 are mirror images of portions of the first heater and the second heater in Q2 and Q3.

10. The substrate support of claim 1 wherein:

the baseplate is cylindrical and comprises four quadrants; and

the first heater and the second heater comprise at least two portions extending through at least two of the four quadrants.

11. The substrate support of claim 1 wherein:

the baseplate is cylindrical and comprises four quadrants; and

the first heater comprises a semicircular portion extending through first and second quadrants of the four quadrants.

12. The substrate support of claim 1 wherein:

the baseplate is cylindrical and comprises four quadrants; and

the first heater comprises two turns in each of the four quadrants.

13. The substrate support of claim 1 wherein:

the baseplate is cylindrical and comprises four quadrants Q1, Q2, Q3, and Q4;

the first heater comprises two terminals in Q1 and Q2; and

the second heater comprises two terminals in Q3 and Q4.

14. The substrate support of claim 1 wherein:

the second heater comprises two semicircular portions that surround the first heater; and

a circular portion that is connected to the two semicircular portions and that surrounds the two semicircular portions.

15. The substrate support of claim 1 wherein:

the baseplate is cylindrical and comprises four quadrants; and

the first heater comprises a semicircular portion extending through first and second quadrants of the four quadrants and comprises two turns in each of the four quadrants.

16. The substrate support of claim 15 wherein the second heater comprises:

two semicircular portions that surround the first heater; and

a circular portion that is connected to the two semicircular portions and that surrounds the two semicircular portions.

17. The substrate support of claim 16 wherein the first heater and the second heater are symmetric around a diameter of the baseplate that intersects only the semicircular portion of the first heater and the circular portion of the second heater.

18. The substrate support of claim 1 wherein the first heater and the second heater comprise heating elements having a D-shaped cross-section.

19. The substrate support of claim 1 wherein the first heater and the second heater comprise heating elements having a circular cross-section.

20. The substrate support of claim 1 further comprising:

a first temperature sensor arranged in the first portion of the baseplate; and

a second temperature sensor arranged in the second portion of the baseplate.

21. The substrate support of claim 20 wherein:

the first temperature sensor is removable; and

the second temperature sensor is embedded in the second portion of the baseplate.

22. A system comprising the substrate support of claim 20 and further comprising a controller configured to:

control the first heater based on a first temperature of the first portion sensed by the first temperature sensor; and

control the second heater based on a second temperature of the second portion sensed by the second temperature sensor.

23. A system comprising the substrate support of claim 20 and further comprising:

a third temperature sensor arranged adjacent to the second temperature sensor in the second portion of the baseplate; and

a controller configured to:

control the first heater based on a first temperature of the first portion sensed by the first temperature sensor; and

control the second heater based on a second temperature of the second portion sensed by the second temperature sensor or the third temperature sensor.