PEDESTALS FOR PROGRESSIVE CLAMPING OF SUBSTRATES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/555,266 filed on February 19, 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 pedestals for progressing clamping of substrates.

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) comprise one or more processing chambers in which substrates such as semiconductor wafers are processed. The processes performed on the substrates can include chemical vapor deposition (CVD), atomic layer deposition (ALD), plasma enhanced (PE) CVD (PECVD), PEALD, thermal ALD (T-ALD), and other processes such as etching processes and PE etching processes. A processing chamber comprises a substrate support (called a pedestal) to support a substrate. During processing, the substrate is clamped to the pedestal using a clamping mechanism. Various clamping mechanisms can be used to clamp the substrate to the pedestal. Examples of clamping mechanisms include electrostatic clamping, vacuum clamping, mechanical clamping, and so on. Depending on the clamping mechanism used, the pedestal can comprise an electrostatic chuck (ESC), vacuum clamping, or another clamping mechanism. In some tools, a computer-controlled robot transfers the substrates between the processing chambers. For example, a substrate on which a first process is performed in a first processing chamber may be transferred to a second processing chamber for performing a second process on the substrate, and so on.

SUMMARY

[0005] A substrate support comprises a plurality of clamping zones arranged in the substrate support. The plurality of clamping zones is configured to clamp a substrate to the substrate support. A controller is configured to cause operation of a first set of clamping zones of the plurality of clamping zones according to a first set of conditions, and to cause operation of a second set of clamping zones of the plurality of clamping zones according to a second set of conditions. The first and second sets of conditions are different.

[0006] In additional features, the controller is configured to cause change in at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate.

[0007] In additional features, the controller is configured to cause setting of the first and second sets of conditions to operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate, and to operate at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate. The first clamping force is zero and the second clamping force is greater than zero. The first and second clamping forces are different. The first and second clamping forces are equal.

[0008] In additional features, the controller is configured to cause a change in a plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply a plurality of clamping forces on the substrate. The controller is configured to cause a change in the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply the plurality of clamping forces on the substrate. The controller is configured to cause a change in the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to sequentially apply the plurality of clamping forces on the substrate. The controller is configured to cause the plurality of conditions to be changed concurrently. The controller is configured to cause the plurality of conditions to be changed at separate times. At least two clamping forces of the plurality of the clamping forces are different from each other. At least two clamping forces of the plurality of the clamping forces are equal. At least one clamping force of the plurality of clamping forces is zero. A first clamping force of the plurality of clamping forces

is zero and a second clamping force of the plurality of clamping forces is greater than zero. At least one clamping force of the plurality of clamping forces in each of the first and second sets of clamping zones is zero. At least one clamping force of the plurality of clamping forces in each of the first and second sets of clamping zones is greater than zero.

[0009] In additional features, the controller is configured to cause measuring of an amount of bow in the substrate; and to cause a change, based on the amount of bow, in at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate.

[0010] In additional features, the controller is configured to cause measuring of an amount of bow in the substrate; cause a change, based on the amount of bow, in at least one condition in the first and second sets of conditions to operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate based on the amount of bow; and to cause a change, irrespective of the amount of bow, in at least one condition in the first and second sets of conditions to at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate.

[0011] In additional features, the plurality of clamping zones comprise a plurality of clamping electrodes, respectively. The first and second sets of conditions are associated with clamping voltages applied to the plurality of clamping electrodes.

[0012] In additional features, the plurality of clamping zones comprise a plurality of vacuum ports, respectively. The first and second sets of conditions control the plurality of vacuum ports.

[0013] In additional features, the plurality of clamping zones are arranged concentrically in the substrate support.

[0014] In still other features, a substrate support for supporting a substrate comprises a plurality of clamping zones arranged in the substrate support. The plurality of clamping zones is configured to clamp the substrate to the substrate support. A controller is configured to control the plurality of clamping zones to clamp the substrate to the substrate support.

[0015] In additional features, the plurality of clamping zones are arranged concentrically in the substrate support. The controller is configured to activate the plurality of clamping zones sequentially from a center of the substrate support in a radial direction.

[0016] In additional features, the plurality of clamping zones are arranged concentrically in the substrate support. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and to activate the plurality of clamping zones sequentially from a center of the substrate support in a radial direction based on the measured amount of bow.

[0017] In additional features, the plurality of clamping zones are arranged concentrically in the substrate support. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and to control at least one of a magnitude of a clamping force and a duration of application of the clamping force.

[0018] In additional features, the plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively. The controller is configured to activate the clamping electrodes sequentially from a center of the substrate support in a radial direction. At least one of the clamping electrodes has a different radial width than others of the clamping electrodes. The clamping electrodes are coplanar. At least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and to activate the plurality of clamping electrodes sequentially from the center of the substrate support in the radial direction based on the measured amount of bow. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and to control at least one of a magnitude of a clamping voltage and a duration of application of the clamping voltage to the clamping electrodes.

[0019] In additional features, the plurality of clamping zones comprises a plurality of sets of vacuum ports arranged concentrically in the plurality of clamping zones, respectively, on a surface of the substrate support that is adjacent to the substrate. The controller is configured to activate the plurality of sets of vacuum ports sequentially from a center of the substrate support in a radial direction.

[0020] In additional features, the surface of the substrate support is curved. The surface of the substrate support is concave. The surface of the substrate support is convex.

[0021] In additional features, the plurality of clamping zones comprises a plurality of sets of vacuum ports arranged concentrically in the plurality of clamping zones, respectively, on a surface of the substrate support that is adjacent to the substrate. The controller is configured to activate the plurality of sets of vacuum ports.

[0022] In additional features, the surface of the substrate support is curved. The surface of the substrate support is concave. The surface of the substrate support is convex.

[0023] The substrate support further comprises a plurality of vacuum channels coupled to the plurality of sets of vacuum ports, respectively; and a plurality of valves coupled to the plurality of vacuum channels, respectively, and to a pump. The controller is configured to turn on the pump and to activate the plurality of valves sequentially. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and to activate the plurality of sets of vacuum ports sequentially from the center of the substrate support in the radial direction based on the measured amount of bow. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and control at least one of a clamping force and a duration of application of the clamping force to at least one of the sets of vacuum ports.

[0024] In additional features, a surface of the substrate support that is adjacent to the substrate comprises a plurality of projections arranged in concentric zones. A height of the projections increases from a center zone to radially outer zones. The plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively. The controller is configured to activate the clamping electrodes sequentially from a center of the substrate support in a radial direction. At least one of the clamping electrodes has a different radial width than others of the clamping electrodes. The clamping electrodes are coplanar. At least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and activate the plurality of clamping electrodes sequentially from the center of the substrate support in the radial direction based on the measured amount of bow. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and control at least one of a magnitude of a clamping voltage and a duration of application of the clamping voltage to the clamping electrodes.

[0025] In still other features, a processing chamber comprises a substrate support configured to support a substrate. The substrate support comprises a first vacuum channel and a first set of vacuum ports arranged in a first clamping zone configured to clamp the substrate to a center region of the substrate support. The substrate support comprises a second vacuum channel and a second set of vacuum ports arranged in a second clamping zone, the second clamping zone surrounding the first clamping zone. The second clamping zone is configured to clamp the substrate to a radially outer region of the substrate support. First and second valves are connected to the first and second vacuum channel, respectively. A third valve is connected to the first and second valves and to a pump. A controller is configured to control the pump and the first, second, and third valves to initially activate the first clamping zone and subsequently activate the second clamping zone to clamp the substrate to the substrate support.

[0026] In additional features, the processing chamber further comprises a fourth valve connected to the second valve and to the processing chamber, the fourth valve configured to equalize pressure in the processing chamber. The controller is configured to, before the substrate is placed on the substrate support, turn on the pump, open the fourth valve, and close the first, second, and third valves. The controller is configured to, after the substrate is placed on the substrate support, activate the first clamping zone by opening the first and third valves while keeping the pump on, the fourth valve open, and the second valve closed. In response to the substrate being bowed, the controller is configured to measure an amount of bow and control at least one of a clamping force and a duration of application of the clamping force before activating the second clamping zone. The controller is configured to, after a period of time, activate the second clamping zone by closing the fourth valve and opening the second valve while keeping the pump on and the first and third valves open. The controller is configured to, after a period of time, in response to the substrate being bowed, measure an amount of bow, and activate the second clamping zone based on the measured amount of bow by closing the fourth valve and opening the second valve while keeping the pump on and the first and third valves open.

[0027] In still other features, a substrate support for supporting a substrate comprises a plurality of clamping zones arranged in the substrate support, the plurality of clamping zones configured to clamp the substrate to the substrate support. A controller is configured to measure an amount of bow in the substrate after the substrate is placed on

the substrate support; and to activate, based on the measured amount of bow, the plurality of clamping zones to clamp the substrate to the substrate support.

[0028] In additional features, the plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively. The controller is configured to activate the clamping electrodes when activating the plurality of clamping zones. At least one of the clamping electrodes has a different radial width than others of the clamping electrodes. The clamping electrodes are coplanar. At least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

[0029] In additional features, the plurality of clamping zones comprises a plurality of sets of vacuum ports arranged concentrically in the plurality of clamping zones, respectively, on a surface of the substrate support that is adjacent to the substrate. The substrate support further comprises a plurality of vacuum channels coupled to the plurality of sets of vacuum ports, respectively; and a plurality of valves coupled to the plurality of vacuum channels, respectively, and to a pump. The controller is configured to turn on the pump and to activate the plurality of valves when activating the plurality of clamping zones.

[0030] In additional features, a surface of the substrate support that is adjacent to the substrate comprises a plurality of projections arranged in concentric zones. A height of the projections increases from a center zone to radially outer zones. The plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively. The controller is configured to activate the clamping electrodes when activating the plurality of clamping zones. At least one of the clamping electrodes has a different radial width than others of the clamping electrodes. The clamping electrodes are coplanar. At least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

[0031] In still other features, a method of clamping a substrate to a substrate support comprises operating a first set of clamping zones of the substrate support according to a first set of conditions and operating a second set of clamping zones of the substrate support according to a second set of conditions. The first and second sets of conditions are different.

[0032] In additional features, the method further comprises changing at least one condition in the first and second sets of conditions to operate at least one clamping zone

of the first and second sets of clamping zones to apply a different clamping force on the substrate.

[0033] In additional features, the method further comprises setting the first and second sets of conditions to operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate; and to operate at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate. The method further comprises setting the first and second sets of conditions to cause the first clamping force to be zero and the second clamping force to be greater than zero. The method further comprises setting the first and second sets of conditions to cause the first and second clamping forces to be different from each other. The method further comprises setting the first and second sets of conditions to cause the first and second clamping forces to be equal.

[0034] In additional features, the method further comprises changing a plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply a plurality of clamping forces on the substrate. The method further comprises changing the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply the plurality of clamping forces on the substrate. The method further comprises changing the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to sequentially apply the plurality of clamping forces on the substrate. The method further comprises changing the plurality of conditions concurrently. The method further comprises changing the plurality of conditions at separate times. The method further comprises changing the plurality of conditions to make at least two clamping forces of the plurality of the clamping forces are different from each other. The method further comprises changing the plurality of conditions to cause at least two clamping forces of the plurality of the clamping forces to be equal. The method further comprises changing the plurality of conditions to cause at least one clamping force of the plurality of clamping forces to be zero. The method further comprises changing the plurality of conditions to cause a first clamping force of the plurality of clamping forces to be zero and a second clamping force of the plurality of clamping forces to be greater than zero. The method further comprises changing the plurality of conditions to cause at least one clamping force of the plurality of clamping forces in each of the first and second sets of clamping zones to be zero. The method further comprises changing the plurality of conditions to cause at least one clamping force

of the plurality of clamping forces in each of the first and second sets of clamping zones to be greater than zero.

[0035] In additional features, the method further comprises measuring an amount of bow in the substrate; and changing, based on the amount of bow, at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate.

[0036] In additional features, the method further comprises measuring an amount of bow in the substrate; changing, based on the amount of bow, at least one condition in the first and second sets of conditions to operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate based on the amount of bow; and changing, irrespective of the amount of bow, at least one condition in the first and second sets of conditions to at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate.

[0037] In additional features, the method further comprises arranging the plurality of clamping zones concentrically in the substrate support.

[0038] In still other features, a substrate support for supporting a substrate comprises a plurality of clamping zones arranged in the substrate support, the plurality of clamping zones configured to clamp the substrate to the substrate support. A controller is configured to activate the plurality of clamping zones in a plurality of steps to progressively clamp the substrate to the substrate support.

[0039] In additional features, the plurality of clamping zones are arranged concentrically in the substrate support. The controller is configured to activate the plurality of clamping zones sequentially from a center of the substrate support in a radial direction when activating the plurality of clamping zones in the plurality of steps.

[0040] In additional features, the plurality of clamping zones are arranged concentrically in the substrate support. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and to activate the plurality of clamping zones sequentially from a center of the substrate support in a radial direction based on the measured amount of bow when activating the plurality of clamping zones in the plurality of steps.

[0041] In additional features, the plurality of clamping zones are arranged concentrically in the substrate support. In response to the substrate being bowed, the controller is configured to measure an amount of bow, and to control at least one of a magnitude of a clamping force and a duration of application of the clamping force in one of the steps prior to progressing to a subsequent step.

[0042] In additional features, the plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively. The controller is configured to activate the clamping electrodes sequentially from a center of the substrate support in a radial direction when activating the plurality of clamping zones in the plurality of steps. At least one of the clamping electrodes has a different radial width than others of the clamping electrodes. The clamping electrodes are coplanar. At least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

[0043] In additional features, in response to the substrate being bowed, the controller is configured to measure an amount of bow, and to activate the plurality of clamping electrodes sequentially from the center of the substrate support in the radial direction based on the measured amount of bow when activating the plurality of clamping zones in the plurality of steps.

[0044] In additional features, in response to the substrate being bowed, the controller is configured to measure an amount of bow, and to control at least one of a magnitude of a clamping voltage and a duration of application of the clamping voltage to the clamping electrodes in one of the steps before progressing to a subsequent step.

[0045] In additional features, the plurality of clamping zones comprises a plurality of sets of vacuum ports arranged concentrically in the plurality of clamping zones, respectively, on a surface of the substrate support that is adjacent to the substrate. The controller is configured to activate the plurality of sets of vacuum ports sequentially from a center of the substrate support in a radial direction when activating the plurality of clamping zones in the plurality of steps. The substrate support further comprises a plurality of vacuum channels coupled to the plurality of sets of vacuum ports, respectively; and a plurality of valves coupled to the plurality of vacuum channels, respectively, and to a pump. The controller is configured to turn on the pump and to activate the plurality of valves sequentially when activating the plurality of clamping zones in the plurality of steps.

[0046] In additional features, in response to the substrate being bowed, the controller is configured to measure an amount of bow, and to activate the plurality of sets of vacuum ports sequentially from the center of the substrate support in the radial direction based on the measured amount of bow when activating the plurality of clamping zones in the plurality of steps.

[0047] In additional features, in response to the substrate being bowed, the controller is configured to measure an amount of bow, and to control at least one of a clamping force and a duration of application of the clamping force to at least one of the sets of vacuum ports in one of the steps before progressing to a subsequent step.

[0048] In additional features, a surface of the substrate support that is adjacent to the substrate comprises a plurality of projections arranged in concentric zones. A height of the projections increases from a center zone to radially outer zones. The plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively. The controller is configured to activate the clamping electrodes sequentially from a center of the substrate support in a radial direction when activating the plurality of clamping zones in the plurality of steps. At least one of the clamping electrodes has a different radial width than others of the clamping electrodes. The clamping electrodes are coplanar. At least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

[0049] In additional features, in response to the substrate being bowed, the controller is configured to measure an amount of bow, and activate the plurality of clamping electrodes sequentially from the center of the substrate support in the radial direction based on the measured amount of bow when activating the plurality of clamping zones in the plurality of steps.

[0050] In additional features, in response to the substrate being bowed, the controller is configured to measure an amount of bow. And control at least one of a magnitude of a clamping voltage and a duration of application of the clamping voltage to the clamping electrodes in one of the steps before progressing to a subsequent step.

[0051] 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

[0052] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0053] FIG. 1 shows an example of a substrate processing system including a processing chamber comprising an electrostatic chuck (ESC) for providing progressive clamping according to the present disclosure;

[0054] FIG. 2 shows an example of a substrate processing system including a processing chamber comprising a pedestal that uses vacuum clamping for providing progressive clamping according to the present disclosure;

[0055] FIG. 3 shows an example of an ESC comprising a first configuration of clamping electrodes for providing progressive clamping according to the present disclosure;

[0056] FIG. 4 shows an example of an ESC comprising a second configuration of clamping electrodes for providing progressive clamping according to the present disclosure;

[0057] FIGS. 5-8 show an example of progressive clamping performed using the ESCs of FIGS. 3 and 4;

[0058] FIG. 9 shows an example of a top view of the ESCs of FIGS. 3 and 4;

[0059] FIGS. 10A-11B show examples of pedestals with different configurations of vacuum ports for providing progressive vacuum clamping according to the present disclosure;

[0060] FIGS. 12-15 show an example of progressive clamping performed using the pedestals of FIGS. 10A-11B;

[0061] FIG. 16 shows an example of an ESC comprising minimum contact areas (MCAs) and comprising the first configuration of clamping electrodes of FIG. 3 for providing progressive clamping according to the present disclosure;

[0062] FIG. 17 shows an example of an ESC comprising MCAs and comprising the second configuration of clamping electrodes of FIG. 4 for providing progressive clamping according to the present disclosure;

[0063] FIGS. 18-21 show an example of progressive clamping performed using the ESCs of FIGS. 16 and 17;

[0064] FIG. 22 shows a first (open-loop) method of providing progressive clamping according to the present disclosure;

[0065] FIG. 23 shows a second (closed-loop) method of providing progressive clamping according to the present disclosure;

[0066] FIG. 24 shows an example of a circuit for measuring bow of a substrate for providing progressive clamping of the substrate according to the present disclosure;

[0067] FIG. 25 shows an equivalent circuit of FIG. 24;

[0068] FIG. 26 shows a method of measuring bow of a substrate for providing progressive clamping of the substrate according to the present disclosure;

[0069] FIGS. 27-31 show an additional example of a pedestal with progressive vacuum clamping according to the present disclosure;

[0070] FIG. 32 shows a method of clamping the substrate to the pedestal of FIG. 27 using progressive clamping;

[0071] FIG. 33 shows a method of clamping the substrate without using progressive clamping;

[0072] FIGS. 34-41 show additional methods of clamping the substrate to any of the pedestals shown in FIGS. 1-26; and

[0073] FIGS. 42-44 show additional examples of pedestals with flat and non-flat profiles.

[0074] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0075] Sometimes substrates being placed on a pedestal for processing can be bowed (curved). The amount of bow (curvature) and therefore the shape of the bowed substrate can vary. For example, a substrate with a high amount of bow can be bowl shaped. A bowed substrate is difficult to clamp onto a pedestal. A bowed substrate can also be prone to developing backside defects. For example, due to the bow, process gases can flow under the bowed region of the substrate causing undesired deposition (or etching) on the backside of the substrate.

[0076] There are ways to improve clamping of bowed substrates. For example, some electrostatic chucks (ESCs) use a bipolar 2D electrode, where a positive voltage is

supplied to a first electrode and a negative voltage is supplied to a second electrode. However, with the 2D bipolar electrode, the entire pedestal experiences the same clamping voltage, which leads to application of the same clamping force on the substrate along the radial direction. One way to clamp a bowed substrate is to increase the clamping voltage applied to the pedestal. However, increasing the clamping voltage increases the voltage gradient across the pedestal material between the two electrodes, which can negatively impact the lifetime (longevity) of the pedestal material.

[0077] Vacuum clamping is typically applied in the center region of the pedestal, which makes the clamping force non-uniform on the substrate along the radial direction. Accordingly, clamping bowed substrates using vacuum clamping can be challenging. Some pedestals employing an ESC also use small projections called minimum contact areas (MCAs) on a top surface of the pedestal on which the substrate is placed. However, the MCAs typically are of the same height. Accordingly, clamping bowed substrates to pedestals with the MCAs has similar challenges as those described above with reference to ESCs.

[0078] The present disclosure provides pedestals that can progressively (sequentially) apply clamping force in the radial direction to clamp bowed substrates regardless of the type of clamping mechanism used. In some embodiments, the progressive clamping may not be performed sequentially and/or in a specific direction (e.g., from center to OD of the pedestal or from OD to center of the pedestal). As described below in detail, the pedestals comprise a plurality of clamping electrodes or vacuum ports arranged concentrically in the pedestal. The clamping force (e.g., clamping voltage or vacuum) is gradually and sequentially applied to the clamping electrodes or vacuum ports from the center region (zone) of the pedestal to radially outer regions (zones) of the pedestal.

[0079] For example, when the bowed substrate is placed on the pedestal, the clamping force is initially applied to the center zone of the pedestal where the bowed substrate contacts the pedestal. The amount of bow changes as the portion of the substrate contacting the center zone of the pedestal conducts heat from the pedestal, which is preheated before placing the substrate on the pedestal. The amount of bow is periodically measured as described below. Based on the change in the amount of bow, the clamping force applied to the center zone of the pedestal is maintained, and clamping force is applied to a next radial zone of the pedestal that is adjacent to (radially outside) the center zone of the pedestal. The process is continued until the substrate is no longer bowed and

is fully clamped to the pedestal. While applying the clamping force to subsequent radial zones, the clamping force can also be changed (e.g., increased or decreased) relative to another clamping zone depending on the measured bow. Further, the time duration of applying the clamping force in each clamping zone can also be varied depending on the measured bow.

[0080] In some embodiments, the clamping force and/or the time duration of applying the clamping force in each clamping zone can be changed regardless of whether the clamping zones are radial. In some embodiments, the clamping force and/or the time duration of applying the clamping force in each clamping zone can be changed regardless of a change in the measured bow. In some embodiments, the clamping force and/or the time duration of applying the clamping force can be changed in the clamping zones in any order.

[0081] For example, in a pedestal comprising an ESC, instead of the 2D bipolar electrode, two or more clamping electrodes are arranged in concentric zones in the ESC and are individually supplied with DC voltages. Instead of applying voltages of the same magnitude but opposite polarity to the two electrodes as in the 2D bipolar electrode, in the multielectrode design of the present disclosure, voltages of different magnitudes but the same polarity are applied to the clamping electrodes. The multielectrode design allows higher voltages to be applied to targeted regions (zones) along the radial direction to clamp substrates with higher bow and with different bow shapes. The multielectrode design can dynamically adjust clamping voltages depending on the shape of the bow of the substrate. Additionally, the electrodes can be embedded in the ESC at different depths to further modulate the clamping force in different regions (zones) of the pedestal.

[0082] The multielectrode design also provides progressive clamping ability by timing application of clamping voltages to different electrodes. For example, the clamping voltage can be initially applied only in the center region, which allows the substrate to absorb heat from the pedestal and reach a higher temperature. Subsequently, an outer clamping electrode can be powered on and so on until the entire substrate is flattened and clamped to the pedestal. Timed clamping can reduce substrate defects by reducing backside scratching as the substrate can be soaked thermally prior to full clamping. Timed clamping can also reduce the risk of a DC breakdown in the gap between the pedestal and the bowed portion of the substrate.

[0083] When vacuum clamping is used, a plurality of vacuum ports can be arranged in a concentric manner similar to the clamping electrodes as described below in detail. The vacuum ports can be activated from the center zone to radially outer zones in the same manner as the clamping voltages are applied to different clamping electrodes in an ESC. When MCAs are used in the ESCs, the height of the MCAs can be changed from the center zone to the radially outer zones. For example, the MCAs in the center zone can be shorter than the MCA's in a first radially outer zone adjacent to the center zone; the MCAs in the first radially outer zone can be shorter than the MCA's in a second radially outer zone adjacent to the first radially outer zone; and so on. Accordingly, if h1, h2, and h3 denote heights of the MCAs in the center zone, the first radially outer zone, and the second radially outer zone, respectively, then h1<h2<h3. In addition, the concentric electrodes arranged in the respective zones in the ESC can be operated as described above.

[0084] The clamping electrodes and vacuum ports in the pedestals can be controlled using an open-loop method or a closed-loop method as follows. In the open-loop method, the clamping zones comprising the clamping electrodes or vacuum ports are activated sequentially from the center zone to the radially outer zones. Sequentially activating the clamping zones progressively flattens the substrate and prevents arcing (in the ESC implementation) or loss of pressure differential (in the vacuum clamping implementation) in the regions where the substrate is far away from the platen of the pedestal. In the closed-loop method, the zone activation scheme can be modified in response to in-situ or ex-situ measured flatness profile of the substrate. The modification may adjust the magnitude (e.g., clamping voltage in the ESC implementation or pressure differential in the vacuum clamping implementation) or the time duration of a clamping step prior to progressing to the next clamping zone in the sequence. These and other features of the present disclosure are described below in further detail.

[0085] In addition, pedestals with a profiled (curved) top surface can be used with progressive clamping. For example, the top surface of the pedestal can have a concave or a convex profile. The curved top surface of the pedestal is called a surface profile of the pedestal. Pedestals with profiled (curved) top surface are called profiled pedestals. Sometimes substrates can have a delta bow (change of substrate bow pre- and post-process). A profiled pedestal can couple the features of a) increasing clamping capability of high bow substrates and b) managing delta bow. With progressive clamping, the two features can be decoupled, where progressive clamping functionality is used to enable

increased clamping capability of high bow substrates, and surface profile of the pedestal is independently employed to manage delta bow.

[0086] Thus, progressive clamping can be an independent knob that can be used to improve clamping. The profile of pedestal is an independent knob for improve clamping ability. Using progressive clamping with the profiled pedestal enhances the ability to clamp bowed substrates. Changing the profile of pedestal impacts delta bow (also changes the delta bow of the substrate before and after running a process).

[0087] The present disclosure is organized as follows. Examples of substrate processing systems including processing chambers comprising an ESC or an ESC with MCAs and comprising a pedestal that uses vacuum clamping are shown and described with reference to FIGS. 1 and 2. Examples of ESCs comprising clamping electrodes providing progressive clamping according to the present disclosure are shown and described with reference to FIGS. 3-9. Examples of pedestals comprising vacuum ports providing progressive clamping according to the present disclosure are shown and described with reference to FIGS. 10A-15. Examples of ESCs comprising MCAs and clamping electrodes for providing progressive clamping according to the present disclosure are shown and described with reference to FIGS. 16-21. Examples of methods of providing progressive clamping according to the present disclosure are shown and described with reference to FIGS. 22 and 23. An example of a circuit for bow measurement for providing progressive clamping according to the present disclosure is shown and described with reference to FIGS. 24 and 25. An example of a method of measuring bow for providing progressive clamping according to the present disclosure is shown and described with reference to FIG. 26. An additional example of a pedestal with progressive vacuum clamping according to the present disclosure is shown and described with reference to FIGS. 27-31. FIG. 32 shows a method of clamping the substrate to the pedestal of FIG. 27 using progressive clamping. FIG. 33 shows a method of clamping the substrate without using progressive clamping. FIGS. 34-41 show additional methods of clamping the substrate to any of the pedestals shown in FIGS. 1-26. FIGS. 42-44 show additional examples of pedestals with flat and non-flat profiles.

EXAMPLE OF PROCESSING CHAMBER COMPRISING ESC

[0088] FIG. 1 shows an example of a substrate processing system 100 including a processing chamber 102 comprising an electrostatic chuck (ESC) 110. For example, the processing chamber 102 comprises a substrate support (also called a pedestal) 104 and

a showerhead 106. The showerhead 106 is connected to a top plate of the processing chamber 102. The substrate processing system 100 may comprise an actuator (not shown) that can move the pedestal 104 vertically up and down relative to the showerhead 106.

[0089] The pedestal 104 comprises a baseplate 108 and the ESC 110. For example, the baseplate 108 is made of a metallic material such as aluminum or an alloy. The ESC 110 comprises a ceramic plate that is disposed on the baseplate 108. The ESC 110 comprises clamping electrodes 112 embedded in the ceramic plate. The substrate processing system 100 comprises a DC power supply 113 to supply power to the clamping electrodes 112. The clamping electrodes 112 provide progressive clamping according to the present disclosure as described below in detail with reference to FIGS. 3-8. An example of a top view of the clamping electrodes 112 is shown and described below with reference to FIG. 9.

[0090] The ESC 110 further comprises MCAs on a top surface of the ESC 110 (i.e., on a top surface of the ceramic plate) on which a substrate 120 is placed. The ESC 110 with MCAs is described below in detail with reference to FIGS. 16-21. The ESC 110 comprises one or more heaters 114 embedded in the ceramic plate to heat the substrate 120. The baseplate 108 comprises one or more cooling channels 116 to cool the pedestal 104. A coolant supply 118 supplies a coolant to the cooling channels 116 to regulate the temperature of the pedestal 104.

[0091] The showerhead 106 supplies one or more gases, gas mixtures, and vaporized precursors into the processing chamber 102. For example, the gases comprise process gases, gas mixtures, vaporized precursors, purge gases, cleaning gases, and so on. While not shown, the showerhead 106 may also comprise one or more heaters and one or more cooling channels that receive the coolant from the coolant supply 118 to regulate the temperature of the showerhead 106.

[0092] The pedestal 104 and the showerhead 106 may also comprise respective temperature sensors 122, 124. A system controller 150 of the substrate processing system 100 receives the temperatures of the pedestal 104 and the showerhead 106 sensed by the temperature sensors 122, 124, respectively. Based on the sensed temperatures, the system controller 150 controls the coolant supply 118, the heaters 114 in the pedestal 104, and the heaters in the showerhead 106 to regulate the temperatures of the pedestal 104 and the showerhead 106.

[0093] The substrate processing system 100 comprises a gas delivery system 130, a vapor delivery system 132, and a manifold 134. The gas delivery system 130 comprises a plurality of gas sources, valves, and mass flow controllers (MFCs) (all not shown) to supply various gases and gas mixtures at various flow rates. The gas delivery system 130 supplies the various gases and gas mixtures to the manifold 134. For example, the various gases comprise process gases, purge gases, cleaning gases, and so on. The vapor delivery system 132 supplies one or more vaporized precursors to the manifold 134. The manifold 134 is connected to the gas delivery system 130, the vapor delivery system 132, and the showerhead 106. The showerhead 106 receives one or more gases, gas mixtures, and vaporized precursors from the manifold 134 and supplies them into the processing chamber 102.

[0094] The substrate processing system 100 comprises a radio frequency (RF) power supply 136. For example, the RF power supply 136 supplies RF power to the showerhead 106. When one or more gases are supplied through the showerhead 106 into the processing chamber 102, the RF power supplied to the showerhead 106 strikes a plasma 140 between the showerhead 106 and the ESC 110.

[0095] The substrate processing system 100 comprises a bow measurement circuit 142. An example of the bow measurement circuit 142 is shown and escribed below in detail with reference to FIGS. 24 and 25. The bow measurement circuit 142 measures an amount of bow of the substrate 120 during progressing clamping as described below in detail. The DC power supply 113 controls the power supplied to the clamping electrodes 112 based on the amount of bow of the substrate 120 measured by the bow measurement circuit 142 during progressing clamping as described below in detail.

[0096] The substrate processing system 100 comprises a valve 144 and a pump 146. The pump 146 is connected to the processing chamber 102 through the valve 144. The pump 146 is connected to an exhaust system (not shown) of the substrate processing system 100. The pump 146 maintains pressure (e.g., vacuum) in the processing chamber 102. The pump 146 also evacuates residual gases and reactants from the processing chamber 102 into the exhaust system of the substrate processing system 100.

[0097] The substrate processing system 100 comprises the system controller 150. The system controller 150 controls all of the components and systems of the substrate processing system 100 described above. For example, the system controller 150 controls the gas delivery system 130, the vapor delivery system 132, the RF power supply 136,

the coolant supply 118, the valve 144 and the pump 146, the actuator, and so on. The system controller 150 controls the DC power supply 113 to control the power supplied to the clamping electrodes 112 based on the bow of the substrate 120 measured by the bow measurement circuit 142 to provide progressing clamping as described below in detail.

EXAMPLE OF PROCESSING CHAMBER USING VACUUM CLAMPING

[0098] FIG. 2 shows an example of a substrate processing system 101 including the processing chamber 102 comprising a pedestal 105 that uses vacuum clamping instead of electrostatic clamping. Elements identified in FIG. 2 with the same reference numerals used in FIG. 1 are not described again for brevity. Although not shown, some of the elements such as heaters and cooling channels shown and described above with reference to FIG. 1 may also be present in the pedestal 105, the showerhead 106, and the substrate processing system 101 shown in FIG. 2. The pedestal 105 provides progressive vacuum clamping according to the present disclosure as follows.

[0099] The pedestal 105 is made of a metallic material such as aluminum or an alloy. Alternatively, the pedestal 105 can be made of a ceramic material. The pedestal 105 comprises a plurality of vacuum channels 160, 162. The vacuum channels 160, 162 are called first and second vacuum channels 160, 162, respectively. The vacuum channels 160, 162 are independent and separate from each other. The pedestal 105 comprises a plurality of vacuum ports disposed on a top surface of the pedestal 105. The vacuum ports can be arranged in different configurations on the top surface of the pedestal 105. Examples of the different configurations of the vacuum ports are shown and described below in detail with reference to FIGS. 10A-11B. The vacuum channels 160, 162 are connected to respective vacuum ports as described below in detail. The vacuum ports can be independently and separately controlled by controlling the vacuum channels 160, 162 to provide progressive vacuum clamping according to the present disclosure as described below in detail with reference to FIGS. 12-15.

[0100] The vacuum channels 160, 162 are connected to respective valves 164, 166. The valves 164, 166 are called the first and second valves, respectively. The first and second valves 164, 166 are connected to the pump 146. The first and second valves 164, 166 are independently and separately controlled by the system controller 150 to provide progressive vacuum clamping according to the present disclosure as described below in detail with reference to FIGS. 12-15.

EXAMPLES OF ESCs PROVIDING PROGRESSIVE CLAMPING

[0101] FIGS. 3 and 4 show examples of ESCs comprising two different configurations of clamping electrodes 112 for providing progressive clamping according to the present disclosure. FIGS. 5-8 show an example of progressive clamping performed using the clamping electrodes 112 in the ESCs of FIGS. 3 and 4. FIG. 9 shows an example of a top view of the ESCs of FIGS. 3 and 4. The ESCs shown in FIGS. 3 and 4 can be used as the ESC 110 shown in FIG. 1.

[0102] FIG. 3 shows an example of the ESC 110 comprising a first configuration of the clamping electrodes 112 for providing progressive clamping according to the present disclosure. For example, the ESC 110 comprises three clamping electrodes 112-1, 112-2, and 112-3 (collectively called the clamping electrodes 112). The three clamping electrodes 112 are concentrically arranged in the ESC 110. The three clamping electrodes 112 are coplanar and lie in a single plane in the ESC 110. While three clamping electrodes 112 are shown as an example, a plurality of clamping electrodes can be used.

[0103] A first clamping electrode 112-1 is disc shaped. The second and third clamping electrodes 112-2 and 112-3 are annular. The first clamping electrode 112-1 is arranged in a center region (also called a center zone or a first zone) of the ESC 110. The first clamping electrode 112-1 has a first diameter. The second clamping electrode 112-2 is arranged in a second region (also called a second zone) of the ESC 110. The second clamping electrode 112-2 surrounds the first clamping electrode 112-1. The second clamping electrode 112-2 has a second inner diameter (ID) and a second outer diameter (OD). The second ID of the second clamping electrode 112-2 is greater than the first diameter of the first clamping electrode 112-1.

[0104] The third clamping electrode 112-3 is arranged in a third region (also called a third zone) of the ESC 110. The third clamping electrode 112-3 surrounds the second clamping electrode 112-2. The third clamping electrode 112-3 has third ID and a third OD. The third ID of the third clamping electrode 112-3 is greater than the second OD of the second clamping electrode 112-2. The third OD of the third clamping electrode 112-3 is less than or equal to a diameter of the ESC 110. The diameter of the ESC 110 is greater than or equal to a diameter of the substrate 120. The third OD of the third clamping electrode 112-3 is less than or equal to a diameter of the substrate 120. For

example, the third OD of the third clamping electrode 112-3 is between the diameter of the ESC 110 and the diameter of the substrate 120.

[0105] The second clamping electrode 112-2 has a first radial width equal to a difference between the second OD and the second ID. The third clamping electrode 112-3 has a second radial width equal to a difference between the third OD and the third ID. For example, the first and second radial widths are the same. Alternatively, the first and second radial widths can be different. For example, the first radial width may be greater or less than the second radial width.

[0106] The clamping electrodes 112 are independently and separately connected to the DC power supply 113 as shown in FIG. 3. The DC power supply 113 supplies voltages v1, v2, and v3 to the respective clamping electrodes 112 to provide progressive clamping according to the present disclosure as described below in detail with reference to FIGS. 5-8. The voltages v1, v2, and v3 are called first, second, and third clamping voltages, respectively. The voltages v1, v2, and v3, when applied to the three clamping electrodes 112, may be equal or different depending on the amount of bow measured in the substrate 120 as described below with reference to FIGS. 5-8. Further, the durations for which the voltages v1, v2, and v3 are applied to fully clamp the substrate 120 to the ESC 110 may also depend on the amount of bow measured in the substrate 120 as described below with reference to FIGS. 5-8.

[0107] FIG. 4 shows an example of the ESC 110 comprising a second configuration of the clamping electrodes 112 for providing progressive clamping according to the present disclosure. Elements identified in FIG. 4 with the same reference numerals used in FIG. 3 are not described again for brevity. The second configuration of the clamping electrodes 112 shown in FIG. 4 differs from the first configuration of the clamping electrodes 112 shown in FIG. 3 as follows.

[0108] In the second configuration, unlike in the first configuration, the three clamping electrodes 112 are not coplanar. Instead, the three clamping electrodes 112 are arranged in three different planes in the ESC 110. For example, the first clamping electrode 112-1 is arranged in a first plane at a first distance (depth) d1 from the top surface of the ESC 110. The second clamping electrode 112-2 is arranged in a second plane at a second distance (depth) d2 from the top surface of the ESC 110. The third clamping electrode 112-3 is arranged in a third plane at a third distance (depth) d3 from the top surface of the ESC 110. $d1 < d2 < d3$.

[0109] While the depths of the clamping electrodes 112 are in the order d1 < d2 < d3 in the example shown, in general, the depth of at least one of the clamping electrodes 112 may be different than the depths of the other clamping electrodes 112. That is, while not shown, in some examples, two of the clamping electrodes 112 may have the same depth but other clamping electrode(s) may have a different depth than the two clamping electrodes. Also, while not shown, in some examples, the depths of the clamping electrodes 112 may not be in the order d1 < d2 < d3; rather, the depths of the clamping electrodes 112 may be in a different order than d1 < d2 < d3. The advantage provided by the different depths of the clamping electrodes 112 in the second configuration of the clamping electrodes 112 is described below.

[0110] FIGS. 5-8 show an example of progressive clamping performed using the ESCs 110 of FIGS. 3 and 4. In FIGS. 5-8, for example, only two clamping electrodes 112-1, 112-2 are shown. The progressing clamping described below can be extended to any number of additional clamping electrodes. Further, while FIGS. 5-8 show an example of the clamping electrodes 112-1, 112-2 that are coplanar as shown in FIG. 3. However, the progressing clamping described below can be extended to the clamping electrodes 112-1, 112-2 and to any number of additional clamping electrodes that are not coplanar as shown in FIG. 4.

[0111] For example, in FIG. 5, the substrate 120 may be bowed when placed on the ESC 110. Initially, the clamping voltages v1 and v2 are zero. Subsequently, the clamping electrodes 112-1, 112-2 are activated to progressively (sequentially) apply clamping force in the radial direction to clamp the bowed substrate 120 to the ESC 110 as described below. Specifically, the clamping voltages v1, v2 are gradually and sequentially applied to the clamping electrodes 112-1, 112-2 to clamp the bowed substrate 120 to the ESC 110 as follows.

[0112] For example, in FIG. 6, when the bowed substrate 120 is placed on the ESC 110, the first clamping voltage v1 is initially applied to the first clamping electrode 112-1 in the center zone of the ESC 110 where the bowed substrate 120 contacts the ESC 110. The second clamping voltage v2 is zero. Accordingly, a first clamping force is applied to a center region (zone) of the bowed substrate 120. No clamping force is applied to a next radial zone of the bowed substrate 120 that is adjacent to (radially outside) the center region (zone) of the bowed substrate 120. The first clamping voltage v1 is applied to the

first clamping electrode 112-1 and the first clamping force is applied to the center region (zone) of the bowed substrate 120 for a first time period.

[0113] In FIG. 7, the amount of bow changes as the portion of the bowed substrate 120 contacting the center zone of the ESC 110 conducts heat for the first time period from the ESC 110, which is preheated before placing the bowed substrate 120 on the ESC 110. The amount of bow is periodically measured as described below in detail with reference to FIGS. 24-26.

[0114] Subsequently (i.e., after the first time period), in FIG. 8, based on the change in the amount of bow, the first clamping force applied to the center region (zone) of the bowed substrate 120 is maintained by continuing to apply the first clamping voltage v1 to the first clamping electrode 112-1. Additionally, the second clamping voltage v2 is applied to the second clamping electrode 112-1. Accordingly, in addition to applying the first clamping force to the center region (zone) of the bowed substrate 120, a second clamping force is applied to the next radial region (zone) of the bowed substrate 120 that is adjacent to (radially outside) the center region (zone) of the bowed substrate 120.

[0115] The first and second clamping voltages v1, v2 are applied to the first and second clamping electrodes 112-1, 112-2, respectively; and the first and second clamping forces are applied to the center region (zone) and the next radial region (zone) of the bowed substrate 120 for a second time period. The amount of bow changes further as an additional portion of the bowed substrate 120 contacting the next radial region (zone) of the ESC 110 conducts heat from the ESC 110. The amount of bow is periodically measured as described below in detail with reference to FIGS. 24-26.

[0116] Eventually, the substrate 120 becomes flat (i.e., has no bow) and is fully clamped to the ESC 110. The first and second clamping voltages v1, v2 may be equal or different depending on the amount of bow measured during the progressive clamping. For example, while applying the clamping force to subsequent radial zones, the clamping force can be changed. For example, the clamping force applied to the subsequent radial zones can be increased or decreased by increasing or decreasing the clamping voltages applied to the subsequent clamping electrodes relative to a prior clamping zone depending on the measured bow. Further, the first and second time periods for which the first and second clamping voltages v1, v2 are applied to fully clamp the substrate 120 to the ESC 110 may also depend on the amount of bow and can be changed based on the

amount of bow. The above methodology can be extended any additional clamping electrodes.

[0117] For example, if the third clamping electrode 112-3 is used, after the second time period, based on the change in the amount of bow, the first and second clamping force applied to the bowed substrate 120 are maintained by continuing to apply the first and clamping voltages v1, v2 to the first and second clamping electrodes 112-1, 112-2. Additionally, the third clamping voltage v3 is applied to the third clamping electrode 112-3 for a third time period. Accordingly, in addition to applying the first and second clamping forces to the center region (zone) and a first radial zone adjacent to (radially outside) the center region of the bowed substrate 120, a third clamping force is applied to a second radial region (zone) of the bowed substrate 120 that is adjacent to (radially outside) the first radial zone.

[0118] The clamping voltages v1, v2, v3 are applied to the first, second, and third clamping electrodes 112-1, 112-2, 112-3, respectively; and the first, second, and third clamping forces are applied to the center region (zone), the first radial zone, and the second radial zone of the bowed substrate 120 for the third time period. The amount of bow changes further as an additional portion of the bowed substrate 120 contacting the ESC 110 conducts heat from the ESC 110. The amount of bow is periodically measured as described below in detail with reference to FIGS. 24-26.

[0119] Eventually, the substrate 120 becomes flat (i.e., has no bow) and is fully clamped to the ESC 110. The clamping voltages v1, v2, v3 may be equal or different depending on the amount of bow measured during the progressive clamping. For example, while applying the clamping force to subsequent radial zones, the clamping force can be changed (e.g., increased or decreased by increasing or decreasing the clamping voltages) relative to another clamping zone depending on the measured bow. Further, the first, second, and third time periods for which the first, second, and third clamping voltages v1, v2, v3 are applied to fully clamp the substrate 120 to the ESC 110 may also depend on the amount of bow and can be changed based on the amount of bow.

[0120] In the multielectrode designs described above, clamping voltages of different magnitudes but the same polarity are applied to the clamping electrodes 112. The multielectrode design allows higher clamping voltages to be applied to targeted regions (zones) of the substrates along the radial direction to clamp substrates with higher bow and with different bow shapes. The DC power supply 113 can dynamically adjust the

clamping voltages depending on the shape of the bow of the substrate 120. Additionally, the different depths of the clamping electrodes 112 can further modulate the clamping force in different regions (zones) of the ESC 110.

[0121] The multielectrode designs described above also provide progressive clamping ability by timing the application of the clamping voltages to different clamping electrodes 112. For example, the clamping voltage can be initially applied only in the center region (zone) of the substrate 120, which allows the substrate 120 to absorb heat from the ESC 110 and reach a higher temperature. Subsequently, a next radially outer clamping electrode (e.g., 112-2) can be powered on and so on until the entire substrate 120 is flattened and clamped to the ESC 110. Timed clamping can reduce substrate defects by reducing backside scratching as the substrate 120 can be soaked thermally prior to full clamping. Timed clamping can also reduce the risk of a DC breakdown in the gap between the ESC 110 and the bowed portion of the substrate 120.

[0122] The clamping electrodes 112 in the ESC 110 can be controlled using an open-loop method or a closed-loop method as described below in detail with reference to FIGS. 22 and 23. Briefly, in the open-loop method, the clamping zones comprising the clamping electrodes 112 are activated sequentially from the center zone to the radially outer zones. Sequentially activating the clamping zones progressively flattens the substrate 120 and prevents arcing in the regions where the substrate 120 is far away from the platen of the pedestal. In the closed-loop method, the zone activation scheme can be modified in response to in-situ or ex-situ measured flatness profile (bow) of the substrate 120. The modification may adjust the magnitude (e.g., the clamping voltage) and/or the time duration of the clamping voltage applied to a clamping electrode prior to progressing to the next clamping zone in the sequence.

[0123] FIG. 9 shows an example of a top view of the ESCs 110 of FIGS. 3 and 4. Elements identified in FIGS. 3 and 4 with the same reference numerals used in FIG. 9 are not described again for brevity.

EXAMPLES OF PEDESTALS USING PROGRESSIVE VACUUM CLAMPING

[0124] FIGS. 10A-11B show examples of pedestals with different configurations of vacuum ports for providing progressive vacuum clamping according to the present disclosure. FIGS. 12-15 show an example of progressive clamping performed using the vacuum channels and the vacuum ports of the pedestals of FIGS. 10A-11B. The pedestals shown in FIGS. 10A-11B can be used as the pedestal 105 shown in FIG. 2.

[0125] FIG. 10A shows an example of a first configuration of vacuum ports in the pedestal 105 shown in FIG. 2. In the first configuration, the top surface of the pedestal 105 comprises three vacuum ports. The three vacuum ports are identified at 170-1, 170-2, and 170-3 and are called first, second, and third vacuum ports, respectively. The first, second, and third vacuum ports 170-1, 170-2, 170-3 are collectively called the three vacuum ports 170.

[0126] The first vacuum port 170-1 is disposed in the center region (also called a center zone or a first zone) of the top surface of the pedestal 105. The second and third vacuum ports 170-2, 170-2 are disposed in a radially outward region (also called a second zone) of the top surface of the pedestal 105 relative to the first vacuum port 170-1. The second and third vacuum ports 170-2, 170-2 lie on a circle having a radius that is smaller than a radius of the top surface of the pedestal 105. The three vacuum ports 170 are collinear. The first vacuum port 170-1 is connected to the first vacuum channel 160. The second and third vacuum ports 170-2, 170-2 are connected to the second vacuum channel 162.

[0127] The top surface of the pedestal 105 comprises a plurality of annular seal bands. For example, the seal bands comprise a first seal band 168-1 and a second seal band 168-2 (collectively called the seal bands 168). The first seal band 168-1 is disposed between the first vacuum port 170-1 and the second and third vacuum ports 170-2, 170-3. The second seal band 168-2 is disposed between an OD of the top surface of the pedestal 105 and the second and third vacuum ports 170-2, 170-3.

[0128] Since the first and second vacuum channels 160, 162 are independent and separate from each other, the first vacuum port 170-1 is also separate and independent from the second and third vacuum ports 170-2, 170-2. Accordingly, the system controller 150 shown in FIG. 2 can sequentially activate the first and second valves 164, 166 shown in FIG. 2 and provide progressive vacuum clamping through the first and second vacuum channels 160, 162 and the three vacuum ports 170 as described below in detail with reference to FIGS. 12-15.

[0129] FIG. 10B shows an example of a second configuration of vacuum ports in the pedestal 105 shown in FIG. 2. In the second configuration, the top surface of the pedestal 105 comprises five vacuum ports. The five vacuum ports are identified at 170-1, 170-2, 170-3, 170-4, 170-5. The five vacuum ports are called first, second, third, fourth, and fifth vacuum ports, respectively, and are collectively called the five vacuum ports 170. The first, second, and third vacuum ports 170-1, 170-2, 170-3 are disposed on the top surface

of the pedestal 105 as described above with reference to FIG. 10A and are therefore not described again for brevity.

[0130] The fourth and fifth vacuum ports 170-4, 170-5 are disposed in a radially outward region of the top surface of the pedestal 105 relative to the first vacuum port 170-1. The fourth and fifth vacuum ports 170-4, 170-5 are disposed orthogonally relative to the second and third vacuum ports 170-2, 170-3. The second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5 lie on a circle having a radius that is smaller than a radius of the top surface of the pedestal 105. The first vacuum port 170-1 and the fourth and fifth vacuum ports 170-4, 170-5 are collinear and are orthogonal to the second and third vacuum ports 170-2, 170-3. The first vacuum port 170-1 is connected to the first vacuum channel 160. The second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5 are connected to the second vacuum channel 162.

[0131] The first seal band 168-1 is disposed between the first vacuum port 170-1 and the second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5. The second seal band 168-2 is disposed between the OD of the top surface of the pedestal 105 and the second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5. While not shown, additional vacuum ports may be disposed in the circle in which the second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5 lie. The additional vacuum ports may also be connected to the second vacuum channel 162.

[0132] Since the first and second vacuum channels 160, 162 are independent and separate from each other, the first vacuum port 170-1 is also separate and independent from the second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5. Accordingly, the system controller 150 shown in FIG. 2 can sequentially activate the first and second valves 164, 166 shown in FIG. 2 and provide progressive vacuum clamping through the first and second vacuum channels 160, 162 and the five vacuum ports 170 as described below in detail with reference to FIGS. 12-15.

[0133] FIG. 11A shows an example of a third configuration of vacuum ports in the pedestal 105 shown in FIG. 2. In the third configuration, the top surface of the pedestal 105 comprises five vacuum ports. The five vacuum ports comprise the first, second, and third vacuum ports 170-1, 170-2, and 170-3 (collectively called the three vacuum ports 170). The three vacuum ports 170 are already described above with reference to FIG. 10A and are therefore not described again for brevity.

[0134] In addition, the five vacuum ports comprise two more vacuum ports called fourth and fifth vacuum ports 172-1, 172-2, respectively. The fourth and fifth vacuum ports 172-1, 172-2 are disposed in the center region of the top surface of the pedestal 105. Specifically, the fourth and fifth vacuum ports 172-1, 172-2 are disposed adjacent to the first vacuum port 170-1 on either side of the first vacuum port 170-1. The three vacuum ports 170 and the fourth and fifth vacuum ports 172-1, 172-2 are collinear. While not shown, additional vacuum ports 170-4, 170-5 may be disposed as shown and described above with reference to FIG. 10B.

[0135] Alternatively, while not shown, the three vacuum ports 170 can be collinear, and the first vacuum port 170-1 and the fourth and fifth vacuum ports 172-1, 172-2 can also be collinear but orthogonal to the three vacuum ports 170. That is, the fourth and fifth vacuum ports 172-1, 172-2 can be arranged on a line that is perpendicular to the line in which the three vacuum ports 170 lie. While not shown, additional vacuum ports 170-4, 170-5 may be disposed as shown and described above with reference to FIG. 10B.

[0136] In either arrangement, the first vacuum port 170-1 and the fourth and fifth vacuum ports 172-1, 172-2 are connected to the first vacuum channel 160. The second and third vacuum ports 170-2, 170-3 (and the additional vacuum ports 170-4, 170-5 if used) are connected to the second vacuum channel 162.

[0137] The first seal band 168-1 is disposed between a first set of vacuum ports including the first vacuum port 170-1 and the fourth and fifth vacuum ports 172-1, 172-2 and a second set of vacuum ports including the second and third vacuum ports 170-2, 170-3. The second seal band 168-2 is disposed between the OD of the top surface of the pedestal 105 and the second and third vacuum ports 170-2, 170-3.

[0138] Since the first and second vacuum channels 160, 162 are independent and separate from each other, the first set of vacuum ports including the first vacuum port 170-1 and the fourth and fifth vacuum ports 172-1, 172-2 is also separate and independent from the second set of vacuum ports including the second and third vacuum ports 170-2, 170-3. Accordingly, the system controller 150 shown in FIG. 2 can sequentially activate the first and second valves 164, 166 shown in FIG. 2 and provide progressive vacuum clamping through the first and second vacuum channels 160, 162 and the first and second sets of vacuum ports as described below in detail with reference to FIGS. 12-15.

[0139] FIG. 11B shows an example of a fourth configuration of vacuum ports in the pedestal 105 shown in FIG. 2. In the fourth configuration, the top surface of the pedestal 105 comprises nine vacuum ports. The nine vacuum ports include the five vacuum ports 170-1, 170-2, 170-3, 170-4, 170-5, which are already described above with reference to FIG. 10B and are therefore not described again for brevity. In addition, the nine vacuum ports comprise the two vacuum ports 172-1, 172-2, which are already described above with reference to FIG. 11A and are therefore not described again for brevity.

[0140] In the fourth configuration, the two vacuum ports 172-1, 172-2 are called sixth and seventh vacuum ports, respectively. In addition, the nine vacuum ports comprise the two more vacuum ports 172-3, 172-4. The two more vacuum ports 172-3, 172-4 are called the eighth and ninth vacuum ports 172-3, 172-4, respectively. The eighth and ninth vacuum ports 172-3, 172-4 are disposed adjacent to the first vacuum port 170-1 and adjacent to the sixth and seventh vacuum ports 172-1, 172-2. The sixth, seventh, eighth, and ninth vacuum ports 172-1, 172-2, 172-3, 172-4 lie in a circle around the first vacuum port 170-1. The sixth, seventh, eighth, and ninth vacuum ports 172-1, 172-2, 172-3, 172-4 may lie at vertices of a square. The square encloses the first vacuum port 170-1. The vertices of the square lie on the circle in which the sixth, seventh, eighth, and ninth vacuum ports 172-1, 172-2, 172-3, 172-4 lie.

[0141] The sixth and seventh vacuum ports 172-1, 172-2 and the first vacuum port 170-1 are collinear. The eighth and ninth vacuum ports 172-3, 172-4 and the first vacuum port 170-1 are also collinear and are orthogonal to the sixth and seventh vacuum ports 172-1, 172-2. Thus, the vacuum ports 170-1, 170-2, 170-3, 172-1, 172-2 are collinear; and the vacuum ports 170-1, 170-4, 170-5, 172-3, 172-4 are collinear. The vacuum ports 170-1, 170-2, 170-3, 172-1, 172-2 are orthogonal to the vacuum ports 170-1, 170-4, 170-5, 172-3, 172-4.

[0142] The first vacuum port 170-1 and the sixth, seventh, eighth, and ninth vacuum ports 172-1, 172-2, 172-3, 172-4 vacuum ports are connected to the first vacuum channel 160. The vacuum ports 170-2, 170-3, 170-4, and 170-5 are connected to the second vacuum channel 162.

[0143] The first seal band 168-1 is disposed between a first set of vacuum ports including the first vacuum port 170-1 and the sixth, seventh, eighth, and ninth vacuum ports 172-1, 172-2, 172-3, 172-4. The second seal band 168-2 is disposed between the OD of the top surface of the pedestal 105 and a second set of vacuum ports including

the second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5. While not shown, additional vacuum ports may be disposed in the circle in which the second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5 lie. The additional vacuum ports may also be connected to the second vacuum channel 162.

[0144] Since the first and second vacuum channels 160, 162 are independent and separate from each other, the first set of vacuum ports including the first vacuum port 170-1 and the sixth, seventh, eighth, and ninth vacuum ports 172-1, 172-2, 172-3, 172-4 is also separate and independent from the second set of vacuum ports including the second, third, fourth, and fifth vacuum ports 170-2, 170-3, 170-4, 170-5. Accordingly, the system controller 150 shown in FIG. 2 can sequentially activate the first and second valves 164, 166 shown in FIG. 2 and provide progressive vacuum clamping through the first and second vacuum channels 160, 162 and the first and second sets of vacuum ports as described below in detail with reference to FIGS. 12-15.

[0145] FIGS. 12-15 show an example of progressive vacuum clamping performed using the pedestal 105 of FIG. 2. In FIGS. 12-15, for example, the pedestal 105 is shown as comprising only the three vacuum ports 170 arranged in the first configuration shown in FIG. 10A. However, the pedestal 105 may comprise any number of vacuum ports arranged in any of the configurations shown and described with reference to FIGS. 10A-11B. The progressing clamping described below can be extended to any number and configuration of vacuum ports (e.g., the configurations shown and described with reference to FIGS. 10B-11B) and any number of vacuum channels.

[0146] In FIGS. 12-15, the valves v1 and v2 are the first and second valves 164 and 166 shown in FIG. 2, respectively. The valves v1 and v2 are called the first and second valves 164, 166, or simply the first and second valves v1, v2, respectively. The downward arrows shown in FIGS. 12-15 indicate the direction of gas flow. The downward arrows shown in FIGS. 12-15 also indicate which valves (e.g., v1, v2) are open. The valves v1 and v2 are controlled to provide progressive vacuum clamping as described below. When the valves v1 and v2 are controlled as described below, the gases in the processing chamber 102 flow through the vacuum ports (shown in FIGS. 10A-11B), the vacuum channels (e.g., 160, 162), the valves (e.g., v1, v2), and the pump 146 into the exhaust system as shown by the arrows in FIGS. 12-15.

[0147] For example, in FIG. 12, the substrate 120 may be bowed when placed on the pedestal 105. Initially, the valves v1 and v2 are closed (i.e., no vacuum clamping force is

applied). Subsequently, the three vacuum ports 170 are activated to progressively (sequentially) apply clamping force in the radial direction to clamp the bowed substrate 120 to the top surface of the pedestal 105 as described below. Specifically, the valves v1, v2 are opened sequentially, and the vacuum clamping force is applied gradually and sequentially through the vacuum ports 170 to clamp the bowed substrate 120 to the pedestal 105 as follows.

[0148] For example, in FIG. 13, when the bowed substrate 120 is placed on the pedestal 105, the first valve v1 is initially opened, and a vacuum clamping force is applied through the first vacuum channel 160 and the first vacuum port 170-1 in the center zone of the pedestal 105 where the bowed substrate 120 contacts the pedestal 105. The second valve v2 is closed. Accordingly, a first clamping force is applied to a center region (zone) of the bowed substrate 120 through the first vacuum channel 160 and the first vacuum port 170-1. Since the second valve v2 is closed, no clamping force is applied to a next radial zone of the bowed substrate 120 that is adjacent to (radially outside) the center region (zone) of the bowed substrate 120. The first clamping force is applied through the first vacuum channel 160 and the first vacuum port 170-1 to the center region (zone) of the bowed substrate 120 by opening the first valve v1 for a first time period.

[0149] In FIG. 14, the amount of bow changes as the portion of the bowed substrate 120 contacting the center zone of the pedestal 105 conducts heat for the first time period from the pedestal 105, which is preheated before placing the bowed substrate 120 on the pedestal 105. The amount of bow is periodically measured as described below in detail with reference to FIGS. 24-26.

[0150] Subsequently (i.e., after the first time period), in FIG. 15, based on the change in the amount of bow, the first clamping force applied to the center region (zone) of the bowed substrate 120 is maintained by keeping the first valve v1 open. Additionally, a second clamping force is applied through the second vacuum channel 162 and the second and third vacuum ports 170-2, 170-3 by opening the second valve v2. Accordingly, in addition to applying the first clamping force to the center region (zone) of the bowed substrate 120, the second clamping force is applied to the next radial region (zone) of the bowed substrate 120 that is adjacent to (radially outside) the center region (zone) of the bowed substrate 120.

[0151] The first and second clamping forces are applied through the first and second vacuum channels 160, 162 and corresponding vacuum ports 170, respectively. The first

and second clamping forces are applied to the center region (zone) and the next radial region (zone) of the bowed substrate 120 for a second time period. The amount of bow changes further as an additional portion of the bowed substrate 120 contacting the center zone of the pedestal 105 conducts heat from the pedestal 105 for the second time period. The amount of bow is periodically measured as described below in detail with reference to FIGS. 24-26.

[0152] Eventually, the substrate 120 becomes flat (i.e., has no bow) and is fully clamped to the pedestal 105. The first and second clamping forces may be equal or different depending on the amount of bow measured during the progressive clamping. For example, while applying the clamping force to subsequent radial zones, the clamping force can be changed relative to another clamping zone depending on the measured bow. For example, the clamping force can be increased or decreased by increasing or decreasing pressure differential between the first and second vacuum channels 160, 162. Further, the first and second time periods for which the first and second clamping forces are applied (i.e., the first and second time periods for which the first and second valves v1, v2 are kept open) to fully clamp the substrate 120 to the pedestal 105 may also depend on the amount of bow and can also be changed based on the amount of bow.

[0153] The above methodology can be extended any additional vacuum ports to provide progressive clamping. For example, in the second configuration shown in FIG. 10B, the first clamping force may be applied through the first vacuum channel 160 and the first vacuum port 170-1, and the second clamping force may be applied through the second vacuum channel 162 and the second through fifth vacuum ports 170-2 through 170-5 in the manner described above with reference to FIGS. 12-15.

[0154] For example, in the third configuration shown in FIG. 11A, the first clamping force may be applied through the first vacuum channel 160 and the vacuum ports 170-1, 172-1, 172-2; and the second clamping force may be through the second vacuum channel 162 and the vacuum ports 170-2, 170-3 in the manner described above with reference to FIGS. 12-15.

[0155] For example, in the fourth configuration shown in FIG. 11B, the first clamping force may be applied through the first vacuum channel 160 and the vacuum ports 170-1 and 172-1 through 172-4; and the second clamping force may be through the second vacuum channel 162 and the vacuum ports 170-2 through 170-5 in the manner described above with reference to FIGS. 12-15.

[0156] Throughout FIGS. 2 and 10A-15, for example, only two sets of vacuum ports and two vacuum channels 160, 162 (and corresponding valves 164, 166) are shown and described. However, additional sets of vacuum ports and additional vacuum channels (and corresponding valves) may be employed in the pedestal 105. The additional vacuum ports, vacuum channels, and valves may be controlled and operated in the manner described above with reference to FIGS. 12-15 to provide progressive clamping.

[0157] In the multiport designs described above, clamping forces of different magnitudes can be applied to targeted regions (zones) of the substrates along the radial direction to clamp substrates with higher bow and with different bow shapes. The multiport designs described above also provide progressive clamping ability by timing the application of the clamping forces to different regions (zones) of the substrates. For example, the clamping force can be initially applied only in the center region (zone) of the substrate 120, which allows the substrate 120 to absorb heat from the pedestal 105 and reach a higher temperature. Subsequently, a next radially outer set of vacuum ports can be activated and so on until the entire substrate 120 is flattened and clamped to the pedestal 105. Timed clamping can reduce substrate defects by reducing backside scratching as the substrate 120 can be soaked thermally prior to full clamping.

[0158] The vacuum ports in the pedestal 105 can be controlled using an open-loop method or a closed-loop method as described below in detail with reference to FIGS. 22 and 23. Briefly, in the open-loop method, the clamping zones comprising the vacuum ports are activated sequentially from the center zone to the radially outer zones. Sequentially activating the clamping zones progressively flattens the substrate 120. In the closed-loop method, the zone activation scheme can be modified in response to in-situ or ex-situ measured flatness profile (bow) of the substrate 120. The modification may adjust the magnitude (e.g., clamping force or pressure) and/or time duration of a clamping force (e.g., timing of valves 164,166) prior to progressing to the next clamping zone in the sequence.

EXAMPLES OF ESCs WITH MCAs PROVIDING PROGRESSIVE CLAMPING

[0159] FIGS. 16 and 17 show examples of ESCs comprising minimum contact areas (MCAs) and comprising different configurations of clamping electrodes for providing progressive clamping according to the present disclosure. FIGS. 18-21 show an example of progressive clamping performed using the ESCs of FIGS. 16 and 17. Elements identified in FIGS. 16-21 with the same reference numerals used in FIGS. 3-8 are not

described again for brevity. The ESCs shown in FIGS. 16 and 17 can be used as the ESC 110/111 shown in FIG. 1.

[0160] FIG. 16 shows an example of an ESC 111 comprising the MCAs and the first configuration of clamping electrodes 112 shown in FIG. 3 for providing progressive clamping according to the present disclosure. The ESC 111 is identical to the ESC 110 shown in FIG. 3 except that in addition to comprising all the features of the ESC 110, the ESC 111 further comprises the MCAs, which are generally shown at 180. The MCAs 180 are small projections extending upwards (e.g., vertically) from the top surface of the ESC 111. The vertical direction is a direction of an axis that is perpendicular to the plane of the top surface of the ESC 111 (e.g., perpendicular to the plane in which the substrate 120 on the top surface of the ESC 111). For example, the MCAs 180 may be cylindrical although the MCAs 180 can be of any other polygonal shape. The substrate 120 rests on the MCAs 180 when the substrate 120 is placed on the ESC 111.

[0161] The MCAs 180 are distributed radially across the top surface of the ESC 111. The MCAs 180 are divided or grouped into a plurality of radial (concentric) zones. The MCAs 180 in each radial zones have different heights. For example, the height of the MCAs 180 increases from the center zone to the radially outer zones. For example, the MCAs in the center zone can be shorter than the MCA's in a first radially outer zone adjacent to the center zone; the MCAs in the first radially outer zone can be shorter than the MCA's in a second radially outer zone adjacent to the first radially outer zone; and so on. Accordingly, if h1, h2, and h3 denote heights of the MCAs in the center zone, the first radially outer zone, and the second radially outer zone, respectively, then $h1<h2<h3$. In general, the height profile of the MCAs 180 can be said to be concave shaped.

[0162] In the example shown in FIGS. 16-21, the ESC 111 comprises the MCAs 180 distributed in only two zones. The center zone (also called a first zone) comprises a first set of MCAs 180-1 having a first height h1. The radially outer zone (also called a second zone) comprises a second set of MCAs 180-2 having a second height h2, where $h2 > h1$. The first and second sets of MCAs 180-1, 180-2 are collectively called the MCAs 180. The height profile of the MCAs 180 is denoted as $h2 > h1$. In addition, the clamping electrodes 112 are arranged in the respective zones in the ESC 111 and can be operated as described above with reference to FIGS. 3-8. While only two MCA zones and three clamping electrodes 112 are shown as an example, a plurality of MCA zones and a plurality of clamping electrodes can be used.

[0163] FIG. 17 shows an example of the ESC 111 comprising the MCAs 180 and the second configuration of clamping electrodes 112 shown in FIG. 4 for providing progressive clamping according to the present disclosure. The ESC 111 is identical to the ESC 110 shown in FIG. 4 except that in addition to comprising all the features of the ESC 110, the ESC 111 further comprises the MCAs 180. The MCAs 180 are already described above with reference to FIG. 16 and are therefore not described again for brevity. In addition, the clamping electrodes 112 are arranged in the respective zones in the ESC 111 and can be operated as described above with reference to FIGS. 3-8. Again, while only two MCA zones and three clamping electrodes 112 are shown as an example, a plurality of MCA zones and a plurality of clamping electrodes can be used.

[0164] FIGS. 18-21 show an example of progressive clamping performed using the ESCs 111 of FIGS. 16 and 17. To provide progressive clamping, the clamping electrodes 112 are controlled (e.g., activated and operated) as described above with reference to FIGS. 3-8. The description is not repeated for brevity. As in FIGS. 5-8, FIGS. 18-21 show an example of progressive clamping performed using the ESCs 111 of FIGS. 16 and 17. As in FIGS. 5-8, in FIGS. 18-21, for example, only two clamping electrodes 112-1, 112-2 are shown. As described above with reference to FIGS. 5-8, the progressing clamping can be extended to any number of additional clamping electrodes in FIGS. 18-21. Further, while FIGS. 18-21 show an example of the clamping electrodes 112-1, 112-2 that are coplanar as shown in FIGS. 3 and 16, the progressing clamping can be extended to the clamping electrodes 112-1, 112-2 and to any number of additional clamping electrodes that are not coplanar as shown in FIGS. 4 and 17.

[0165] The height profile of the MCAs 180 (e.g., $h2 > h1$) generally matches the flatness profile (bow) of the bowed substrate 120. Accordingly, as the bowed substrate 120 flattens during progressive clamping, more bottom surface of the bowed substrate 120 contacts more of the profiled MCAs 180, and more heat transfers from the ESC 111 through the profiled MCAs 180 to the bowed substrate120. Consequently, the bowed substrate 120 flattens and clamps faster on the ESC 111 shown in FIGS. 16-21 than on the ESC 110 shown in FIGS. 3-8. The improved heating of the bowed substrate 120 due to the profiled MCAs 180 reduces the magnitudes and durations of the clamping voltages applied to the clamping electrodes 112 during progressive clamping.

EXAMPLES OF METHODS OF PROVIDING PROGRESSIVE CLAMPING

[0166] In the following methods, sequential clamping of radial clamping zones is described only as an example. In some embodiments, the clamping zones may not be radial, and the progressive clamping may not be performed sequentially. Instead, the progressive clamping may be performed by activating the clamping zones in any order. Further, in some embodiments, before performing progressive clamping, the clamping zones may already be active or turned on (e.g., some amount of clamping force may be already applied to the clamping zones), and only the clamping force applied to the clamping zones (e.g., clamping voltages applied to the clamping electrodes in the clamping zones in an ESC) may be changed sequentially or in any order. Accordingly, progressive clamping generally comprises changing clamping force in different clamping zones in any order.

[0167] FIG. 22 shows a first (open-loop) method 200 of providing progressive clamping according to the present disclosure. FIG. 23 shows a second (closed-loop) method 250 of providing progressive clamping according to the present disclosure. For example, the first and second methods 200, 250 may be performed by the system controller 150 shown in FIGS. 1 and 2. The first and second methods 200, 250 may be performed by the system controller 150 using any of the ESCs 110, 111 described above with reference to FIGS. 3-8 and 16-21 and using any of the pedestal 105 designs described above with reference to FIGS. 10A-15. The first method 200 provides progressive clamping without measuring the bow in the substrate. The second method 250 provides progressive clamping based on measured bow of the substrate as described below.

[0168] In FIG. 22, in the first method 200, at 202, a substrate (e.g., the substrate 120) is placed on a pre-heated substrate support (e.g., the ESC 110 or 111, or the pedestal 105). At 204, if an ESC is used, the method 200 activates a clamping electrode (e.g., 112-1 shown in FIGS. 3-8 and 16-21) in the center zone of the substrate support (e.g., the ESC 110 or 111). Alternatively, if vacuum clamping is used, the method 200 activates one or more vacuum ports (e.g., 170-1, 172-1 through 172-4 shown in FIGS. 10A-15) in the center zone of the substrate support (e.g., the pedestal 105).

[0169] At 206, the method 200 waits for a time period for the substrate to absorb heat from the substrate support. As described above with reference to FIGS. 5-8, 18-21, and 12-15, when the substrate is bowed, the center portion of the bowed substrate contacts the center zone of the substrate support and absorbs heat from the center zone of the substrate support, which reduces the amount of bow in the substrate.

[0170] At 208, after waiting for the time period, the method 200 activates a radially subsequent clamping electrode (e.g., 112-2 shown in FIGS. 3-8 and 16-21) or radially subsequent vacuum ports (e.g., 170-2 through 170-5 shown in FIGS. 10A-15). The method 200 repeats the procedure of sequentially activating radially subsequent clamping electrodes or vacuum ports until the substrate is fully flattened and clamped to the substrate support.

[0171] In FIG. 23, in the second method 250, plasma is used to measure bow in the substrate as described below with reference to FIGS. 24-26. The method 250 performs progressive clamping based on the measured bow of the substrate as follows.

[0172] At 252, the method 250 supplies an inert gas and strikes plasma in the processing chamber 102. At 254, a substrate (e.g., the substrate 120) is placed on a pre-heated substrate support (e.g., the ESC 110 or 111, or the pedestal 105). At 256, if an ESC is used, the method 250 activates a clamping electrode (e.g., 112-1 shown in FIGS. 3-8 and 16-21) in the center zone of the substrate support (e.g., the ESC 110 or 111). Alternatively, if vacuum clamping is used, the method 250 activates one or more vacuum ports (e.g., 170-1, 172-1 through 172-4 shown in FIGS. 10A-15) in the center zone of the substrate support (e.g., the pedestal 105).

[0173] At 258, the method 250 waits for a time period for the substrate to absorb heat from the substrate support. As described above with reference to FIGS. 5-8, 18-21, and 12-15, when the substrate is bowed, the center portion of the bowed substrate contacts the center zone of the substrate support and absorbs heat from the center zone of the substrate support, which reduces the amount of bow in the substrate.

[0174] At 260, after waiting for the time period, the method 250 measures the amount of bow in the substrate. The bow measurement if described below in detail with reference to FIGS. 24-26. At 262, the method 250 determines if a bow if detected (i.e., if a bow if still present) in the substrate.

[0175] If the substrate is till bowed, at 264, the method 250 activates a radially subsequent clamping electrode (e.g., 112-2 shown in FIGS. 3-8 and 16-21) or radially subsequent vacuum ports (e.g., 170-2 through 170-5 shown in FIGS. 10A-15). The method 250 also adjusts one or more of the following: In an ESC (e.g., 110 or 111), a clamping voltage of one or more clamping electrodes (e.g., previously activated electrode(s), electrode being presently activated, or both), and/or a time duration for which the electrode being presently activated is activated before performing next step. In

the pedestal 105 (i.e., when vacuum clamping is used), a pressure differential between the previously activated vacuum port(s) and the vacuum port(s) being presently activated, and/or a time duration for which the vacuum port(s) being presently activated is activated before performing next step. The method 250 returns to step 260. The method 250 repeats the procedure of sequentially activating radially subsequent clamping electrode(s) or vacuum port(s) until the substrate is fully flattened (i.e., no bow is detected in the substrate) and is fully clamped to the substrate support.

[0176] If the substrate is not bowed, at 266, the method 250 activates any remaining clamping electrode(s) or vacuum port(s). At this point, the substrate is fully flattened and clamped to the substrate support, and the method 250 ends.

EXAMPLE OF CIRCUIT AND METHOD FOR BOW MEASUREMENT

[0177] FIG. 24 shows an example of a circuit 300 for measuring bow of a substrate for providing progressive clamping of the substrate according to the present disclosure. FIG. 25 shows an equivalent circuit of the circuit 300 shown in FIG. 24. FIG. 26 shows a method 350 of measuring bow of a substrate for providing progressive clamping of the substrate according to the present disclosure. For example, the method 350 may be performed by the system controller 150 shown in FIGS. 1 and 2 using the circuit 300 shown in FIGS. 24 and 25. The method 350 is performed in step 260 of the method 250 shown in FIG. 23.

[0178] In FIG. 24, to measure the amount of bow in a substrate during progressive clamping (e.g., in the method 250), plasma is used as follows. For example, as described above with reference to FIGS. 1 and 2, the showerhead 106 can supply a gas into the processing chamber 102. The RF power supply 136 can supply RF power to the showerhead 106, which functions as RF electrode, to strike plasma 140. The plasma 140 is struck between the showerhead 106 and the substrate 120 (i.e., between the showerhead 106 and the pedestal 104/105).

[0179] As shown in FIG. 24, the plasma 140 can be represented as a reactive electrical component having an impedance. For example, the plasma 140 can be represented as a resistance Rp connected in series with a capacitance Cp. Depending on the change in the bow in the substrate 120 as the substrate 120 conducts heat from the substrate support (104/105) during progressive clamping, the capacitance Cp and therefore the impedance of the plasma 140 changes. Accordingly, by measuring a change in the impedance of the plasma 140, the amount of bow in the substrate 120 can be measured.

A bow measurement circuit 142 can measure the amount of bow in the substrate 120 by measuring the change in the impedance of the plasma 140.

[0180] Additionally, a capacitance Cs is formed between the substrate 120 and the substrate support (104/105). The capacitance Cs also changes depending on the change in the bow in the substrate 120 as the substrate 120 conducts heat from the substrate support (104/105) during progressive clamping. Accordingly, by measuring a change in the capacitance Cs, the amount of bow in the substrate 120 can be measured. The bow measurement circuit 142 can measure the amount of bow in the substrate 120 by measuring the change in the capacitance Cs.

[0181] FIG. 25 shows the equivalent circuit of the circuit 300 shown in FIG. 24. In the equivalent circuit, the impedance of the plasma 140 is in series with the capacitance Cs. Accordingly, the capacitance Cp, the resistance Rp, and the capacitance Cs are connected to each other in series. The series combination of the capacitance Cp, the resistance Rp, and the capacitance Cs is connected between the RF power supply 136 and a reference potential (e.g., ground).

[0182] For example, the bow measurement circuit 142 shown in FIG. 24 can comprise a voltage and current (V/I) measurement circuit 143. The V/I measurement circuit 143 can measure the bow in the substrate 120 during progressive clamping (e.g., in the method 250) as follows. For example, the V/I measurement circuit 143 can use a method 350 shown and described below with reference to FIG. 26 to measure the bow in the substrate 120 during progressive clamping. For example, the system controller 150 shown in FIGS. 1 and 2 can comprise the bow measurement circuit 142 shown in FIG. 24, which can comprise the V/I measurement circuit 143 shown in FIG. 25.

[0183] When the plasma 140 is struck, the V/I measurement circuit 143 measures the voltage and current (V and I) components of the RF power supplied by the RF power supply 136 to the RF electrode (e.g., the showerhead 106) to strike the plasma 140. The V/I measurement circuit 143 determines a phase angle between the V and I components. The V/I measurement circuit 143 determines an impedance seen by the RF power supply 136 based on the measured V and I components. The phase angle and the impedance change depending on the change in the bow in the substrate 120 as the substrate 120 conducts heat from the substrate support (104/105) during progressive clamping.

[0184] The V/I measurement circuit 143 compares the phase angle and/or the impedance with respective calibrated values. The calibrated values are determined a

priori for a fully clamped substrate. The V/I measurement circuit 143 determines the amount of bow in the substrate 120 based on the comparison (i.e., based on the difference between the determined and calibrated phase angle and/or based on the difference between the determined and calibrated impedance).

[0185] FIG. 26 shows the method 350 of measuring bow of the substrate 120 for providing progressive clamping of the substrate 120 according to the present disclosure. At 352, the method 350 measures the voltage and current (V and I) components of the RF power supplied by the RF power supply 136 (see FIGS. 1 and 2) to the RF electrode (e.g., the showerhead 106 shown in FIGS. 1 and 2) to strike plasma (see step 252 of the method 250 shown in FIG. 23).

[0186] At 354, the method 350 determines a phase angle between the V and I components. At 356, the method 350 determines an impedance seen by the RF power supply 136 based on the measured V and I components. At 358, the method 350 compares the phase angle and/or the impedance with respective calibrated values. The calibrated values are determined a priori for a fully clamped substrate. At 360, the method 350 determines the amount of bow in the substrate based on the comparison (i.e., based on the difference between the determined phase angle and/or the impedance, and respective calibrated values).

ADDITIONAL EXAMPLE OF PEDESTAL WITH PROGRESSIVE VACUUM CLAMPING

[0187] FIGS. 27-32 show an additional example of a pedestal using progressive vacuum clamping according to the present disclosure. For example, FIG. 27 shows a pedestal comprising two vacuum clamping zones. FIGS. 28-31 show an example of progressively clamping the substrate 120 to the pedestal of FIG. 27 using progressive vacuum clamping. FIG. 32 shows a method of progressive vacuum clamping using the pedestal of FIG. 27 to progressively clamp the substrate 120 to the pedestal of FIG. 27 as shown in FIGS. 28-31.

[0188] In FIG. 27, a pedestal 400 comprises a baseplate (also called a base portion) 402 and a stem (also called a stem portion) 404. The baseplate 402 and the stem 404 are cylindrical. The baseplate 402 has a greater diameter than the stem 404. The pedestal 400 is made of a metallic material such as aluminum or an alloy. Alternatively, the pedestal 400 can be made of a ceramic material. The pedestal 400 also comprises the seal bands 168 shown in FIGS. 28-31. The seal bands 168 are already described above with reference to FIG. 2 and are therefore not described again for brevity. For

example, the pedestal 400 can be used in the processing chamber 102 shown in FIG. 2. Other details of the processing chamber 102 shown and described with reference to FIG. 2 are omitted but are presumed to be present in FIG. 27.

[0189] For example, the pedestal 400 comprises two vacuum zones. A first vacuum zone is circular and extends from the center of the baseplate 402 to a first radial distance r1 from the center of the baseplate 402. A second vacuum zone is annular and extends radially from r1 to an outer diameter (OD) of the baseplate 402. Thus, the radial width of the second vacuum zone is (OD – r1). A plurality of vacuum ports can be provided in the first and second vacuum zones. Examples of the vacuum ports are already described above with reference to FIGS. 10A-11B and are therefore not described again for brevity.

[0190] An adapter 410 is attached to the bottom of the pedestal 400 (e.g., to the bottom of the processing chamber 102 under the stem 404). For example, the adapter 410 may be cylindrical or may be of any other shape. A perimeter of the adapter 410 is greater than the diameter of the stem 404. The adapter 410 provides routing for vacuum channels as follows.

[0191] A first vacuum channel 412 extends through the adapter 410, the stem 404, and the baseplate 402. The first vacuum channel 412 is in fluid communication with a first set of vacuum ports (e.g., see FIGS. 10A-11B) in the first vacuum zone. The first vacuum channel 412 is connected to a first end of a first valve V1. The first end of the first valve V1 is in fluid communication with the first vacuum channel 412.

[0192] A second vacuum channel (e.g., a manifold) 414 surrounds the stem 404. The second vacuum channel 414 extends radially under the baseplate 402 and to the OD of the baseplate 402. A first end of the second vacuum channel 414 is attached to the bottom of the processing chamber 102. The first end of the second vacuum channel 414 has the same perimeter as the adapter 410. A second end of the second vacuum channel 414 is attached to the bottom of the baseplate 402. The second end of the second vacuum channel 414 has the same perimeter as the baseplate 402. The second vacuum channel 414 is in fluid communication with a second set of vacuum ports (e.g., see FIGS. 10A-11B) in the second vacuum zone.

[0193] The baseplate 402 comprises an annular channel 413 in the second vacuum zone. The annular channel 413 is in fluid communication with the second vacuum channel 414 and with the second set of vacuum ports (e.g., see FIGS. 10A-11B) in the second vacuum zone.

[0194] A conduit 415 extends through the adapter 410 and is in fluid communication with the second vacuum channel 414. The conduit 415, the second vacuum channel 414, and the annular channel 413 can be collectively called the second vacuum channel 414. The conduit 415 is connected to a first end of a second valve V2. The first end of the second valve V2 is in fluid communication with the conduit 415 and with the second vacuum channel 414.

[0195] An equalizing valve Ve has a first end in fluid communication with the first end of the second valve and has a second end connected to the processing chamber 102. The equalizing valve Ve equalizes the pressure in the processing chamber 102 during progressive vacuum clamping as described below.

[0196] Second ends of the first and second valves V1, V2 are connected to a first end of a third valve V3. A second end of the third valve V3 is connected to the pump 146. The valves V1, V2, V3, and Ve are controlled by the system controller 150 to progressively clamp the substrate 120 as described below.

[0197] FIGS. 28-32 show an example of providing progressive clamping using two vacuum zones. However, the description of FIGS. 28-32 can be extended to more than two vacuum zones. For each additional vacuum zone, an additional vacuum channel, an additional valve Vn, and an additional equalizing valve Ve-n can be provided. For example, a first end of the additional valve Vn can be connected to an nth vacuum channel for an nth vacuum zone, a second end of the additional valve Vn can be connected to the first end of the valve V3, a first end of the additional equalizing valve Ve-n can be connected to the first end of the additional valve Vn, and a second end of the additional equalizing valve Ve-n can be connected to the processing chamber 102. The valves Vn and Ve-n can be controlled similar to the valves V2 and Ve as described below to provide progressive clamping using n vacuum zones.

[0198] The configuration of the valves V1, V2, V3, and Ve shown in FIG. 27 and the control scheme for controlling these valves described below with reference to FIG. 32 requires a single vacuum manifold from the third valve V3 to the pump 146 instead of requiring multiple separate vacuum manifolds between the pump 146 and each of the valves V1 and V2 for each of the vacuum zones. The configuration and the control scheme also eliminate the need for a pressure controller that would be otherwise needed for performing vacuum clamping.

[0199] The progressive vacuum clamping is described below by jointly referring to FIGS. 27-32. Accordingly, FIGS. 28-31 are not separately described for brevity. In the description of FIGS. 28-32, an open valve is on, and a closed valve is off. A method 450 shown in FIG. 32 for progressively clamping the substrate 120 to the pedestal 400 can be performed by the system controller 150 as follows. The pump 146 is presumed on throughout the method 450.

[0200] In FIG. 32, at 452, initially (i.e., before placing the substrate 120 on the pedestal 400, see FIG. 28), the system controller 150 closes the valves V1, V2, V3, and opens the valve Ve. The valve Ve equalizes the pressure in the processing chamber 102. At 454, after the substrate 120 is placed on the pedestal 400 (see FIG. 29), the system controller 150 opens the valves V1 and V3. The valve V2 remains closed, and the valve Ve remains open. By opening the valves V1 and V3, the first vacuum zone is activated, and a clamping force is applied to a center portion of the substrate 120.

[0201] The system controller 150 waits for a time period before activating the radially subsequent second vacuum zone. By waiting for the time period, the system controller 150 allows the substrate 120 to absorb (soak) heat from the pedestal 400 through the center portion of the substrate 120 in contact with the pedestal 400 (see FIG. 30).

[0202] After the time period, the system controller 150 activates the second vacuum zone as follows without measuring the bow in the substrate 120 if the system controller 150 is using the open loop method 200 of progressive clamping described above with reference to FIG. 22. Alternatively, after time period, the system controller 150 activates the second vacuum zone as follows by measuring the bow in the substrate 120 if the system controller 150 is using the closed loop method 250 of progressive clamping described above with reference to FIG. 23. If using the closed loop method 250, the system controller 150 measures the bow in the substrate as described above with reference to FIGS. 24-26 and activates the second vacuum zone based on the measured bow as follows.

[0203] At 456, the system controller 150 activates the second vacuum zone by opening the valve V2 and closing the valve Ve. The first vacuum zone remains activated. Thus, when the second vacuum zone is activated, the valves V1, V2, V3 are open (on), and the valve Ve is closed (off). The substrate 120 is fully clamped to the pedestal 400 as shown in FIG. 31.

[0204] In some examples, progressive clamping described above may not be used to clamp the substrate to the pedestal. For example, after the substrate is placed on the pedestal and the bow in the substrate is measured, progressively clamping the substrate may be unnecessary if the substrate is not bowed (e.g., if the amount of bow in the substrate is less than or equal to a predetermined threshold amount of bow). Accordingly, all the clamping zones can be activated at once (i.e., not sequentially as in progressive clamping. All the clamping zones can be activated at once regardless of the clamping mechanism used. Any of the clamping mechanisms described above for progressively clamping the substrate to the substrate support can be used to clamp the substrate to the support without using progressive clamping (i.e., by activating all the clamping zones at once, together, or concurrently).

[0205] FIG. 33 shows a method 500 of clamping the substrate without using progressive clamping (i.e., by activating all the clamping zones at once, together, or concurrently). For example, the method 500 for clamping the substrate 120 to any of the pedestals described above can be performed by the system controller 150 as follows. The pump 146 is presumed on throughout the method 500.

[0206] At 502, the substrate 120 is placed on the pedestal. For example, the pedestal can be any of the substrate supports and pedestals using any of the clamping mechanisms already described above. At 504, the system controller 150 measures an amount of bow in the substrate 120. For example, the system controller 150 can use any of the circuits and methods described above to measure the amount of bow in the substrate 120.

[0207] At 506, the system controller 150 determines if the substrate 120 is bowed. For example, the system controller 150 may determine that the substrate 120 is not bowed if the measured amount of bow in the substrate 120 is less than or equal to a predetermined threshold amount of bow. The system controller 150 may determine that the substrate 120 is bowed if the measured amount of bow in the substrate 120 is greater than the predetermined threshold amount of bow.

[0208] If the substrate 120 is not bowed, at 508, the system controller 150 activates all the clamping zones (e.g., all the clamping electrodes, or vacuum ports in the substrate support) at once to clamp the substrate 120 to the substrate support. If the substrate 120 is bowed, at 510, the method 500 proceeds to step 206 of the method 200 shown in FIG.

22 and follows the procedure described above to progressively clamp the substrate 120 to the substrate support.

ADDITIONAL EMBODIMENTS

[0209] While progressive clamping including sequential control of clamping zones is described above with reference to FIGS. 1-26, a substrate can be clamped to any of the substrate supports shown in FIGS. 1-26 using techniques described below. For example, the system controller 150 can clamp the substrate 120 to any of these pedestals as follows.

[0210] The substrate can be clamped to the pedestal by changing conditions in different clamping zones as described below. For example, for an ESC, the conditions can comprise clamping voltages, clamping durations, clamping states (activated or non-activated), and so on of clamping electrodes in clamping zones. For a pedestal using vacuum clamping, the conditions can comprise vacuum port states (activated or non-activated) in one or more clamping zones, states of valves associated with one or more clamping zones, clamping durations of one or more clamping zones, and so on. The substrate can be clamped to the pedestal by changing the conditions for operating different clamping zones, which changes the clamping forces applied by the clamping zones to the substrate. For example, in the ESCs described above, the substrate can be clamped to the ESC by changing clamping voltages applied to clamping electrodes in different clamping zones. In the pedestals using vacuum clamping described above, the substrate can be clamped to the pedestal by setting vacuum ports in different clamping zones to different conditions. For example, the substrate can be clamped to the pedestal by controlling the vacuum ports in different clamping zones (e.g., by controlling the vacuum channels and valves described above).

[0211] The following description applies to the structures and configurations of all of the pedestals shown and described above with reference to FIGS. 1-26. The structures and configurations of these pedestals are therefore not described again for brevity. Instead, only the manner of controlling the structures (e.g., clamping electrodes and vacuum ports) in the various pedestal configurations is described below. Also, the following description applies equally to controlling the clamping electrodes of the ESCs and the vacuum ports of the pedestals using vacuum clamping described above.

[0212] For example, a plurality of clamping zones in a pedestal can comprise a first set of clamping zones and a second set of clamping zones. Each of the first and second sets

of clamping zones comprises at least one clamping zone. In an ESC, each clamping zone comprises a clamping electrode as described above with reference to relevant figures in FIGS. 1-26. In a pedestal using vacuum clamping, each clamping zone comprises one or more vacuum ports, which are coupled to a corresponding vacuum channel and valve(s), as described above with reference to relevant figures in FIGS. 1-26.

[0213] The first set of clamping zones can be operated using a first set of conditions. The second set of clamping zones can be operated using a second set of conditions. Each of the first and second sets of conditions comprises at least one condition to operate a clamping zone. For example, the at least one condition comprises a clamping voltage that can be applied to a clamping electrode in a clamping zone in any of the ESCs described above. For example, the first set of conditions comprises a first set of voltages that can be applied to clamping electrodes in the first set of clamping zones, and the second set of conditions comprises a second set of voltages that can be applied to clamping electrodes in the second set of clamping zones. Thus, the first and second sets of conditions control clamping voltages that can be applied to the clamping electrodes in different clamping zones, which in turn control the clamping forces that can be applied by the different clamping zones to the substrate.

[0214] For pedestals using vacuum clamping described above, the at least one condition controls one or more vacuum ports in a clamping zone. For example, in pedestals using vacuum clamping, the first set of conditions controls vacuum ports in the first set of clamping zones, and the second set of conditions controls vacuum ports in the second set of clamping zones. The conditions for controlling vacuum ports can comprise controlling corresponding vacuum channels and valves described above. Thus, the first and second sets of conditions control the vacuum ports in different clamping zones, which in turn control the clamping forces that can be applied by the different clamping zones to the substrate.

[0215] In some examples, the first and second sets of conditions can be the same (e.g., when all clamping zones are similarly controlled). Alternatively, the second set of conditions can be different than the first set of conditions (e.g., when the clamping zones are differently controlled). Any of the first and second sets of conditions can be changed by the system controller 150 to operate any of the first and second sets of clamping zones in various ways as follows.

[0216] For example, initially (i.e., before placing the substrate on the pedestal or when the substrate is placed on the pedestal), the first and second sets of conditions can be set as follows. The first and second sets of conditions can be set such that the clamping forces applied by one or more clamping zones in the first and second sets of clamping zones can be zero, or can be less than or equal to the clamping forces needed to fully clamp the substrate to the pedestal, or a combination of both. Any of the first and second sets of conditions can be changed to fully clamp the substrate to the pedestal as described below.

[0217] For example, one or more clamping forces applied by one or more clamping zones in one or both sets of clamping zones can be adjusted (increased and/or decreased). One or more clamping zones in one or both sets of clamping zones can be turned off (i.e., no clamping force is applied). One or more clamping zones in one or both sets of clamping zones can be turned on (i.e., a clamping force is applied). One or more clamping zones in the first set of clamping zones can be turned off (i.e., no clamping force is applied), and one or more clamping zones in the second set of clamping zones can be turned on (i.e., a clamping force is applied). Any combination of these and other types of changes in the conditions can be used. Any of these conditions can be changed concurrently or at different times until the substrate is fully clamped to the pedestal.

[0218] The conditions in the clamping zones can be changed in any order (i.e., without following a sequence). Alternatively, the conditions in the clamping zones can be changed sequentially (e.g., from center to OD of the pedestal or from OD to center of the pedestal). In some examples, the conditions in the first set of clamping zones can be changed in a first order, and the conditions in the second set of clamping zones can be changed in a second order that is different than the first order. For example, the first order may be any order (i.e., without following a sequence), and the second order may be a sequential order (e.g., from center to OD of the pedestal or from OD to center of the pedestal). For example, the first order may be a first sequential order (e.g., from center to OD of the pedestal), and the second order may be a second sequential order (e.g., from OD to center of the pedestal). The conditions in the first and second sets of clamping zones can be changed in an alternating order. The conditions in the first set of clamping zones can be unchanged, and the conditions in the second set of clamping zones can be changed sequentially or in any other order. Any of these conditions can be changed concurrently or at different times as described above. Any combination of these and other types of changes can be used until the substrate is fully clamped to the pedestal.

[0219] The conditions in the clamping zones can be changed as described above based on an amount of bow or a change in the amount of bow in the substrate. Alternatively, the conditions in the clamping zones can be changed regardless (i.e., irrespective or independently) of the amount of bow or a change in the amount of bow in the substrate (i.e., not in response to a change in the amount bow in the substrate). For example, the conditions in the first set of clamping zones can be changed based on the amount of bow or a change in the amount of bow in the substrate, and the conditions in the second set of clamping zones can be changed regardless of the amount of bow or a change in the amount of bow in the substrate. For example, the conditions in the first set of clamping zones can be unchanged, and the conditions in the second set of clamping zones can be changed based on the amount of bow or a change in the amount of bow in the substrate. For example, the conditions in the first set of clamping zones can be unchanged, and the conditions in the second set of clamping zones can be changed regardless of the amount of bow or a change in the amount of bow in the substrate. Any of these conditions can be changed concurrently or at different times as described above. Any of these conditions can be changed sequentially or in any order as described above. Any combination of these types of changes can be used until the substrate is fully clamped to the pedestal.

[0220] FIGS. 34-41 show various methods of controlling the clamping zones of the pedestals by changing the conditions in the clamping zones as described above. For example, the system controller 150 can perform these methods to clamp the substrate 120 to any of the pedestals shown and described above with reference to FIGS. 1-26. The system controller 150 can perform these methods to control the clamping electrodes in the clamping zones of the ESCs. The system controller 150 can perform these methods to control the vacuum ports in the clamping zones of the pedestals that use vacuum clamping. The system controller 150 can perform these methods to control voltages applied to the clamping electrodes in the clamping zones of the ESCs. The system controller 150 can perform these methods to control the vacuum channels and valves coupled to the vacuum ports in the clamping zones of the pedestals that use vacuum clamping.

[0221] In an ESC, controlling or operating a clamping zone comprises controlling or operating a clamping electrode in the clamping zone by changing a condition in the clamping zone. In a pedestal using vacuum clamping, controlling or operating a clamping zone comprises controlling or operating one or more vacuum ports in the clamping zone by changing a condition in the clamping zone, which in tun comprises controlling or

operating a vacuum channel and one or more valves corresponding to the clamping zone by changing a condition in the clamping zone. The system controller 150 can perform the methods shown in FIGS. 34-41 separately or in any combination to fully clamped the substrate to the pedestal.

[0222] FIG. 34 shows a method 600 of controlling clamping zones of a pedestal (e.g., any pedestal shown in FIGS. 1-26). At 602, a substrate (e.g., the substrate 120) is placed on the pedestal. At 604, the system controller 150 operates a first set of clamping zones according to a first set of conditions. At 606, the system controller 150 operates a second set of clamping zones according to a second set of conditions. The system controller 150 continues operating the first and second sets of clamping zones by controlling the first and second sets of conditions in many ways described above and also shown and described below with reference to FIGS. 36-41. The system controller 150 continues operating the first and second sets of clamping zones by controlling the first and second sets of conditions until the substrate is fully clamped to the pedestal.

[0223] FIG. 35 shows a method 610 of controlling clamping zones of a pedestal (e.g., any pedestal shown in FIGS. 1-26). Steps 612, 614, and 616 are identical to steps 602, 604, and 606, respectively. At 618, the system controller 150 changes at least one condition of the first and second sets of conditions to change at least one clamping force applied to the substrate by at least one clamping zone of the first and second sets of clamping zones. The system controller 150 changes the at least one condition to operate the at least one clamping zone differently than a prior value of the at least one condition. Accordingly, the at least one clamping zone applies a different clamping force than a previously applied clamping force by the at least one clamping zone to the substrate.

[0224] In some examples, changing the at least one condition of the first and second sets of conditions can comprise the following operations performed by the system controller 150. For example, the system controller 150 can set the first and second sets of conditions to operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate. The system controller 150 can set the first and second sets of conditions to operate at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate.

[0225] In one example, the first clamping force can be zero (e.g., the first clamping zone can be turned off or deactivated), and the second clamping force can be greater than

zero (e.g., the second clamping zone can be turned on or activated). In another example, the first and second clamping forces can be different. For example, the first clamping force can be increased, and the second clamping force can be decreased. The amount of the opposite change in the first and second clamping forces can be the same or different. In another example, each of the first and second clamping forces can be changed (e.g., increased or decreased) by different amounts. In another example, the first and second clamping forces can be equal.

[0226] The system controller 150 can change the first and second clamping forces in many other ways. For example, the system controller 150 can change the at least one condition to operate the at least one clamping zone using a variety of methods shown and described below with reference to subsequent figures. For example, the system controller 150 can change the order in which the clamping zones are controlled. Additionally or alternatively, the system controller 150 can change the timings of changing the conditions to control the clamping zones. Additionally or alternatively, the system controller 150 can change the at least one condition to operate the at least one clamping zone depending on the amount of bow in the substrate or independently of the amount of bow in the substrate. The system controller 150 continues to control the first and second sets of conditions to change the clamping forces applied by the first and second sets of clamping zones using any combination of these methods until the substrate is fully clamped to the pedestal.

[0227] FIG. 36 shows one method of performing step 618. At 620, the system controller 150 changes a plurality of conditions of the first and second sets of conditions to operate the first and second sets of clamping zones to apply a plurality of clamping forces on the substrate. At 622, the system controller 150 changes the plurality of conditions of the first and second sets of conditions to operate the first and second sets of clamping zones to apply the plurality of clamping forces on the substrate in any order. In addition to changing the plurality of conditions in any order, the system controller 150 can change the plurality of conditions of the first and second sets of conditions in any of the various ways described above, which are not described again for brevity.

[0228] FIG. 37 shows another method of performing step 618. Step 630 is the same as step 620. At 632, the system controller 150 changes the plurality of conditions of the first and second sets of conditions to operate the first and second sets of clamping zones to sequentially apply the plurality of clamping forces on the substrate. In addition to

changing the plurality of conditions sequentially, the system controller 150 can change the plurality of conditions of the first and second sets of conditions in any of the various ways described above, which are not described again for brevity.

[0229] FIG. 38 shows another method of performing step 618. Step 640 is the same as step 620. At 642, the system controller 150 changes the plurality of conditions of the first and second sets of conditions to operate the first and second sets of clamping zones concurrently. In addition to changing the plurality of conditions concurrently, the system controller 150 can change the plurality of conditions of the first and second sets of conditions in any of the various ways described above, which are not described again for brevity.

[0230] FIG. 39 shows another method of performing step 618. Step 650 is the same as step 620. At 652, the system controller 150 changes the plurality of conditions of the first and second sets of conditions at separate times to operate the first and second sets of clamping zones. In addition to changing the plurality of conditions at separate times, the system controller 150 can change the plurality of conditions of the first and second sets of conditions in any of the various ways described above, which are not described again for brevity.

[0231] Using the methods of FIGS. 36-39, the system controller 150 can control the clamping zones to provide clamping forces in various ways. For example, at least two clamping forces provided by at least two clamping zones can be different from each other. For example, at least one clamping zone can be turn off and at least one clamping zone can be turned on using one or more schemes described in these methods. For example, the clamping forces of at least two clamping zones can be increased and/or decreased by different amounts using one or more schemes described in these methods. For example, one clamping zone can be turned off and the clamping force of another clamping zone can be increased or decreased relative to a prior value, and so on.

[0232] Further, using the methods of FIGS. 36-39, at least two clamping forces provided by at least two clamping zones can be made equal. For example, at least two clamping zones can be turned off using one or more schemes described in these methods. Alternatively, at least two clamping zones can be turned on using one or more schemes described in these methods. The clamping forces of at least two clamping zones can be increased and/or decreased by the same amount using the one or more schemes described in these methods, and so on. Any combination of these methods can

be used to control clamping forces applied by the clamping zones to the substrate in different ways described above.

[0233] FIG. 40 shows another method of performing step 618. At 660, the system controller 150 measures the amount of bow or a change in the amount of bow in the substrate as described above with reference to FIGS. 24-26. At 662, the system controller 150 changes, based on the amount of bow or the change in the amount of bow, at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate than a prior value. In addition to changing the at least one condition based on the amount of bow, the system controller 150 can change the at least one condition in any of the various ways described above, including those shown and described above with reference to FIGS. 36-39, which are not described again for brevity.

[0234] FIG. 41 shows another method of performing step 618. Steps 670 and 672 are the same as steps 660 and 662. At 674, the system controller 150 changes, irrespective (i.e., regardless or independently) of the amount of bow or the change in the amount of bow, at least one other condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate than a prior value. In addition to changing the at least one other condition independently of (i.e., not in response to) the amount of bow or the change in the amount of bow, the system controller 150 can change the at least one other condition also in any of the various ways described above, including those shown and described above with reference to FIGS. 36-39, which are not described again for brevity.

[0235] Thus, progressive clamping can be performed in any of the substrate supports shown in FIGS. 1-26 as described in the description of FIGS. 1-26. Further, perform progressive clamping can be performed in any of the substrate supports shown in FIGS. 1-26 using various other methods as described above in the description of FIGS. 34-41.

[0236] FIGS. 42-44 show additional examples of pedestals according to the present disclosure. FIG. 42 shows an example of a pedestal with a flat top surface and two sets of vacuum ports that can be activated simultaneously using a single vacuum channel. FIGS. 43 and 44 show examples of pedestals with a curved top surface. FIG. 43 shows an example of a pedestal with a concave top surface. FIG. 43 shows an example of a pedestal with a convex top surface. For example, the pedestals shown in FIGS. 43 and

44 include two sets of vacuum ports that can be activated simultaneously using a single vacuum channel.

[0237] While the pedestals in FIGS. 43 and 44 with a curved top surface are shown with a single vacuum channel activating two sets of vacuum ports simultaneously, these pedestals can employ a plurality of vacuum channels and a plurality of sets of vacuum ports. Accordingly, the pedestals shown in the preceding figures that use progressive vacuum clamping can include the curved top surfaces shown in FIGS. 43 and 44. In pedestals employing the curved top surfaces shown in FIG. 43 or 44 and employing a plurality of vacuum channels and a plurality of sets of vacuum ports, the plurality of sets vacuum ports can be activated separately to achieve progressive clamping as described with reference to preceding figures. Alternatively, in these pedestals employing the curved top surfaces shown in FIG. 43 or 44 and employing a plurality of vacuum channels and a plurality of sets of vacuum ports, the plurality of sets of vacuum ports can be activated simultaneously to clamp the substrate as described with reference to preceding figures.

[0238] FIG. 42 shows a pedestal 700. The pedestal 700 comprises a baseplate (also called a base portion) 702 and a stem (also called a stem portion) 704. A top surface 706 of the baseplate 702 is flat. The baseplate 702 and the stem 704 are cylindrical. The baseplate 702 has a greater diameter than the stem 704. The pedestal 700 is made of a metallic material such as aluminum or an alloy. Alternatively, the pedestal 700 can be made of a ceramic material. For example, the pedestal 400 can be used in the processing chamber 102 shown in FIG. 2. Other details of the processing chamber 102 shown and described with reference to FIG. 2 are omitted but are presumed to be present in FIG. 42.

[0239] For example, the pedestal 700 comprises two vacuum zones. A first vacuum zone is circular and extends from the center of the baseplate 702 to a first radial distance r1 from the center of the baseplate 702. A second vacuum zone is circular and extends radially from r1 to an outer diameter (OD) of the baseplate 402. Thus, the radial width of the second vacuum zone is (OD – r1). A plurality of sets of vacuum ports 713-1, 713-2 can be provided in the first and second vacuum zones, respectively. The first and second vacuum zones are concentric. The plurality of sets of vacuum ports 713-1, 713-2 (e.g., called the first and second sets of vacuum ports, respectively) are also concentric.

[0240] An adapter 710 is attached to the bottom of the pedestal 700 (e.g., to the bottom of the processing chamber 102 under the stem 704). For example, the adapter 710 may be cylindrical or may be of any other shape. A perimeter of the adapter 710 is greater than the diameter of the stem 704. The adapter 710 provides routing for one or more vacuum channels as follows.

[0241] A vacuum channel (e.g., a manifold) 714 surrounds the stem 704. The vacuum channel 714 extends radially under the baseplate 702 and to the OD of the baseplate 702. A first (lower) end of the vacuum channel 714 is attached to adapter 710. The first end of the vacuum channel 714 has the same perimeter as the adapter 710. A second (upper) end of the vacuum channel 714 is attached to the bottom of the baseplate 702. The second end of the vacuum channel 714 has the same perimeter as the baseplate 702. The vacuum channel 714 is in fluid communication with the first and second sets of vacuum ports in the first and second vacuum zones.

[0242] A conduit 712 extends through the adapter 710 into the vacuum channel 714 and is in fluid communication with the vacuum channel 714. The conduit 712 is also in fluid communication with the first set of vacuum ports 713-1 in the first vacuum zone and with the second set of vacuum ports 713-2 in the second vacuum zone. The conduit 712, the vacuum channel 714, and the first and second sets of vacuum ports 713-1, 713-2 can be collectively called the vacuum channel 714.

[0243] The conduit 712 is connected to a first end of a valve V. The first end of the first valve V is in fluid communication with the conduit 712. A second end of the valve V is connected to the pump 146. The valve V and the pump 146 are controlled by the system controller 150. The system controller 150 controls the valve V and the pump 146 to simultaneously activate the first and second sets of vacuum ports 713-1, 713-2 to clamp the substrate 120 (not shown) to the top surface 706 of the pedestal.

[0244] FIG. 43 shows a pedestal 701 with a concave top surface 707. Other description of the pedestal 700 applies equally to the pedestal 701 and is therefore nor repeated for brevity.

[0245] FIG. 44 shows a pedestal 703 with a convex top surface 709. Other description of the pedestal 700 applies equally to the pedestal 701 and is therefore nor repeated for brevity.

[0246] Again, while the pedestals 701 and 703 of FIGS. 43 and 44 are shown with a single vacuum channel 714 activating two sets of vacuum ports 713-1, 713-2 simultaneously, these pedestals can employ a plurality of vacuum channels and a plurality of sets of vacuum ports. Accordingly, the pedestals shown in the preceding figures that use progressive vacuum clamping can include the pedestals 701 and 703 of FIGS. 43 and 44. In pedestals employing the curved top surfaces shown in FIG. 43 or 44 and employing a plurality of vacuum channels and a plurality of sets of vacuum ports, the plurality of sets vacuum ports can be activated separately to achieve progressive clamping as described with reference to preceding figures. Alternatively, in these pedestals employing the curved top surfaces shown in FIG. 43 or 44 and employing a plurality of vacuum channels and a plurality of sets of vacuum ports, the plurality of sets of vacuum ports can be activated simultaneously to clamp the substrate as described with reference to preceding figures.

[0247] The pedestals 701 and 703 with curved (concave and convex) top surfaces are called profiled pedestals. These profiled pedestals 701 and 703 can couple the features of a) increasing clamping capability of high bow substrates and b) managing delta bow (described above). When the profiled pedestals 701 and 703 are used with progressive clamping, the two features a) and b) can be decoupled, where progressive clamping functionality is used to enable increased clamping capability of high bow substrates, and the curved surface profile of the pedestals 701 and 703 is independently employed to manage delta bow.

[0248] Thus, progressive clamping can be an independent knob that can be used to improve clamping. The curved profile of pedestals 701 and 703 is an independent knob for improve clamping ability. Using progressive clamping with the profiled pedestals 701 and 703 enhances the ability to clamp bowed substrates. Changing the profile of pedestals from flat top surface to curved top surface impacts delta bow (also changes the delta bow of the substrate before and after running a process).

[0249] 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.

[0250] 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.

[0251] 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."

[0252] 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.

[0253] 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.

[0254] 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).

[0255] 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.

[0256] 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.

[0257] 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.

[0258] 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.

[0259] 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.

[0260] 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 comprising:

a plurality of clamping zones arranged in the substrate support, the plurality of clamping zones configured to clamp a substrate to the substrate support; and

a controller configured to:

cause operation of a first set of clamping zones of the plurality of clamping zones according to a first set of conditions; and

cause operation of a second set of clamping zones of the plurality of clamping zones according to a second set of conditions,

wherein the first and second sets of conditions are different.

2. The substrate support of claim 1 wherein the controller is configured to cause change in at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate.

3. The substrate support of claim 1 wherein the controller is configured to cause setting of the first and second sets of conditions to:

operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate; and

operate at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate.

4. The substrate support of claim 3 wherein the first clamping force is zero and the second clamping force is greater than zero.

5. The substrate support of claim 3 wherein the first and second clamping forces are different.

6. The substrate support of claim 3 wherein the first and second clamping forces are equal.

7. The substrate support of claim 1 wherein the controller is configured to cause a change in a plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply a plurality of clamping forces on the substrate.

8. The substrate support of claim 7 wherein the controller is configured to cause a change in the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply the plurality of clamping forces on the substrate.

9. The substrate support of claim 7 wherein the controller is configured to cause a change in the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to sequentially apply the plurality of clamping forces on the substrate.

10. The substrate support of claim 7 wherein the controller is configured to cause the plurality of conditions to be changed concurrently.

11. The substrate support of claim 7 wherein the controller is configured to cause the plurality of conditions to be changed at separate times.

12. The substrate support of claim 7 wherein at least two clamping forces of the plurality of the clamping forces are different from each other.

13. The substrate support of claim 7 wherein at least two clamping forces of the plurality of the clamping forces are equal.

14. The substrate support of claim 7 wherein at least one clamping force of the plurality of clamping forces is zero.

15. The substrate support of claim 7 wherein a first clamping force of the plurality of clamping forces is zero and a second clamping force of the plurality of clamping forces is greater than zero.

16. The substrate support of claim 7 wherein at least one clamping force of the plurality of clamping forces in each of the first and second sets of clamping zones is zero.

17. The substrate support of claim 7 wherein at least one clamping force of the plurality of clamping forces in each of the first and second sets of clamping zones is greater than zero.

18. The substrate support of claim 1 wherein the controller is configured to:

cause measuring of an amount of bow in the substrate; and

cause a change, based on the amount of bow, in at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate.

19. The substrate support of claim 1 wherein the controller is configured to:

cause measuring of an amount of bow in the substrate;

cause a change, based on the amount of bow, in at least one condition in the first and second sets of conditions to operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate based on the amount of bow; and

cause a change, irrespective of the amount of bow, in at least one condition in the first and second sets of conditions to at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate.

20. The substrate support of claim 1 wherein the plurality of clamping zones comprise a plurality of clamping electrodes, respectively; and wherein the first and second sets of conditions are associated with clamping voltages applied to the plurality of clamping electrodes.

21. The substrate support of claim 1 wherein the plurality of clamping zones comprise a plurality of vacuum ports, respectively; and wherein the first and second sets of conditions control the plurality of vacuum ports.

22. The substrate support of claim 1 wherein the plurality of clamping zones are arranged concentrically in the substrate support.

23. A substrate support for supporting a substrate comprising:

a plurality of clamping zones arranged in the substrate support, the plurality of clamping zones configured to clamp the substrate to the substrate support; and

a controller configured to control the plurality of clamping zones to clamp the substrate to the substrate support.

24. The substrate support of claim 23 wherein:

the plurality of clamping zones are arranged concentrically in the substrate support; and

the controller is configured to activate the plurality of clamping zones sequentially from a center of the substrate support in a radial direction.

25. The substrate support of claim 23 wherein the plurality of clamping zones are arranged concentrically in the substrate support and wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

activate the plurality of clamping zones sequentially from a center of the substrate support in a radial direction based on the measured amount of bow.

26. The substrate support of claim 23 wherein the plurality of clamping zones are arranged concentrically in the substrate support and wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

control at least one of a magnitude of a clamping force and a duration of application of the clamping force.

27. The substrate support of claim 23 wherein:

the plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively; and

the controller is configured to activate the clamping electrodes sequentially from a center of the substrate support in a radial direction.

28. The substrate support of claim 27 wherein at least one of the clamping electrodes has a different radial width than others of the clamping electrodes.

29. The substrate support of claim 27 wherein the clamping electrodes are coplanar.

30. The substrate support of claim 27 wherein at least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

31. The substrate support of claim 27 wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

activate the plurality of clamping electrodes sequentially from the center of the substrate support in the radial direction based on the measured amount of bow.

32. The substrate support of claim 27 wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

control at least one of a magnitude of a clamping voltage and a duration of application of the clamping voltage to the clamping electrodes.

33. The substrate support of claim 23 wherein:

the plurality of clamping zones comprises a plurality of sets of vacuum ports arranged concentrically in the plurality of clamping zones, respectively, on a surface of the substrate support that is adjacent to the substrate; and

the controller is configured to activate the plurality of sets of vacuum ports sequentially from a center of the substrate support in a radial direction.

34. The substrate support of claim 33 wherein the surface of the substrate support is curved.

35. The substrate support of claim 33 wherein the surface of the substrate support is concave.

36. The substrate support of claim 33 wherein the surface of the substrate support is convex.

37. The substrate support of claim 23 wherein:

the plurality of clamping zones comprises a plurality of sets of vacuum ports arranged concentrically in the plurality of clamping zones, respectively, on a surface of the substrate support that is adjacent to the substrate; and

the controller is configured to activate the plurality of sets of vacuum ports.

38. The substrate support of claim 37 wherein the surface of the substrate support is curved.

39. The substrate support of claim 37 wherein the surface of the substrate support is concave.

40. The substrate support of claim 37 wherein the surface of the substrate support is convex.

41. The substrate support of claim 33 further comprising:

a plurality of vacuum channels coupled to the plurality of sets of vacuum ports, respectively; and

a plurality of valves coupled to the plurality of vacuum channels, respectively, and to a pump,

wherein the controller is configured to turn on the pump and to activate the plurality of valves sequentially.

42. The substrate support of claim 33 wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

activate the plurality of sets of vacuum ports sequentially from the center of the substrate support in the radial direction based on the measured amount of bow.

43. The substrate support of claim 33 wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

control at least one of a clamping force and a duration of application of the clamping force to at least one of the sets of vacuum ports.

44. The substrate support of claim 23 wherein:

a surface of the substrate support that is adjacent to the substrate comprises a plurality of projections arranged in concentric zones, wherein a height of the projections increases from a center zone to radially outer zones;

the plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively; and

the controller is configured to activate the clamping electrodes sequentially from a center of the substrate support in a radial direction.

45. The substrate support of claim 44 wherein at least one of the clamping electrodes has a different radial width than others of the clamping electrodes.

46. The substrate support of claim 44 wherein the clamping electrodes are coplanar.

47. The substrate support of claim 44 wherein at least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

48. The substrate support of claim 44 wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

activate the plurality of clamping electrodes sequentially from the center of the substrate support in the radial direction based on the measured amount of bow.

49. The substrate support of claim 44 wherein in response to the substrate being bowed, the controller is configured to:

measure an amount of bow; and

control at least one of a magnitude of a clamping voltage and a duration of application of the clamping voltage to the clamping electrodes.

50. A processing chamber comprising:

a substrate support configured to support a substrate, the substrate support comprising:

a first vacuum channel and a first set of vacuum ports arranged in a first clamping zone configured to clamp the substrate to a center region of the substrate support; and

a second vacuum channel and a second set of vacuum ports arranged in a second clamping zone, the second clamping zone surrounding the first clamping zone, the second clamping zone configured to clamp the substrate to a radially outer region of the substrate support;

first and second valves connected to the first and second vacuum channel, respectively;

a third valve connected to the first and second valves and to a pump; and

a controller configured to control the pump and the first, second, and third valves to initially activate the first clamping zone and subsequently activate the second clamping zone to clamp the substrate to the substrate support.

51. The processing chamber of claim 50 further comprising a fourth valve connected to the second valve and to the processing chamber, the fourth valve configured to equalize pressure in the processing chamber.

52. The processing chamber of claim 51 wherein the controller is configured to, before the substrate is placed on the substrate support, turn on the pump, open the fourth valve, and close the first, second, and third valves.

53. The processing chamber of claim 52 wherein the controller is configured to, after the substrate is placed on the substrate support, activate the first clamping zone by opening the first and third valves while keeping the pump on, the fourth valve open, and the second valve closed.

54. The processing chamber of claim 53 wherein in response to the substrate being bowed, the controller is configured to measure an amount of bow and control at least one of a clamping force and a duration of application of the clamping force before activating the second clamping zone.

55. The processing chamber of claim 53 wherein the controller is configured to, after a period of time, activate the second clamping zone by closing the fourth valve and opening the second valve while keeping the pump on and the first and third valves open.

56. The processing chamber of claim 53 wherein the controller is configured to, after a period of time, in response to the substrate being bowed, measure an amount of bow, and activate the second clamping zone based on the measured amount of bow by closing the fourth valve and opening the second valve while keeping the pump on and the first and third valves open.

57. A substrate support for supporting a substrate comprising:

a plurality of clamping zones arranged in the substrate support, the plurality of clamping zones configured to clamp the substrate to the substrate support; and

a controller configured to:

measure an amount of bow in the substrate after the substrate is placed on the substrate support; and

activate, based on the measured amount of bow, the plurality of clamping zones to clamp the substrate to the substrate support.

58. The substrate support of claim 57 wherein:

the plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively; and

the controller is configured to activate the clamping electrodes when activating the plurality of clamping zones.

59. The substrate support of claim 58 wherein at least one of the clamping electrodes has a different radial width than others of the clamping electrodes.

60. The substrate support of claim 58 wherein the clamping electrodes are coplanar.

61. The substrate support of claim 58 wherein at least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

62. The substrate support of claim 57 wherein the plurality of clamping zones comprises a plurality of sets of vacuum ports arranged concentrically in the plurality of clamping zones, respectively, on a surface of the substrate support that is adjacent to the substrate.

63. The substrate support of claim 62 further comprising:

a plurality of vacuum channels coupled to the plurality of sets of vacuum ports, respectively; and

a plurality of valves coupled to the plurality of vacuum channels, respectively, and to a pump,

wherein the controller is configured to turn on the pump and to activate the plurality of valves when activating the plurality of clamping zones.

64. The substrate support of claim 57 wherein:

a surface of the substrate support that is adjacent to the substrate comprises a plurality of projections arranged in concentric zones, wherein a height of the projections increases from a center zone to radially outer zones;

the plurality of clamping zones comprises a plurality of clamping electrodes arranged concentrically in the plurality of clamping zones, respectively; and

the controller is configured to activate the clamping electrodes when activating the plurality of clamping zones.

65. The substrate support of claim 64 wherein at least one of the clamping electrodes has a different radial width than others of the clamping electrodes.

66. The substrate support of claim 64 wherein the clamping electrodes are coplanar.

67. The substrate support of claim 64 wherein at least one of the clamping electrodes is arranged at a different depth in the substrate support than others of the clamping electrodes.

68. A method of clamping a substrate to a substrate support, the method comprising:

operating a first set of clamping zones of the substrate support according to a first set of conditions; and

operating a second set of clamping zones of the substrate support according to a second set of conditions, wherein the first and second sets of conditions are different.

69. The method of claim 68 further comprising changing at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate.

70. The method of claim 68 further comprising setting the first and second sets of conditions to:

operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate; and

operate at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate.

71. The method of claim 70 further comprising setting the first and second sets of conditions to cause the first clamping force to be zero and the second clamping force to be greater than zero.

72. The method of claim 70 further comprising setting the first and second sets of conditions to cause the first and second clamping forces to be different from each other.

73. The method of claim 70 further comprising setting the first and second sets of conditions to cause the first and second clamping forces to be equal.

74. The method of claim 68 further comprising changing a plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply a plurality of clamping forces on the substrate.

75. The method of claim 74 further comprising changing the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to apply the plurality of clamping forces on the substrate.

76. The method of claim 74 further comprising changing the plurality of conditions of the first and second sets of conditions used to operate the first and second sets of clamping zones to sequentially apply the plurality of clamping forces on the substrate.

77. The method of claim 74 further comprising changing the plurality of conditions concurrently.

78. The method of claim 74 further comprising changing the plurality of conditions at separate times.

79. The method of claim 74 further comprising changing the plurality of conditions to make at least two clamping forces of the plurality of the clamping forces are different from each other.

80. The method of claim 74 further comprising changing the plurality of conditions to cause at least two clamping forces of the plurality of the clamping forces to be equal.

81. The method of claim 74 further comprising changing the plurality of conditions to cause at least one clamping force of the plurality of clamping forces to be zero.

82. The method of claim 74 further comprising changing the plurality of conditions to cause a first clamping force of the plurality of clamping forces to be zero and a second clamping force of the plurality of clamping forces to be greater than zero.

83. The method of claim 74 further comprising changing the plurality of conditions to cause at least one clamping force of the plurality of clamping forces in each of the first and second sets of clamping zones to be zero.

84. The method of claim 74 further comprising changing the plurality of conditions to cause at least one clamping force of the plurality of clamping forces in each of the first and second sets of clamping zones to be greater than zero.

85. The method of claim 68 further comprising:

measuring an amount of bow in the substrate; and

changing, based on the amount of bow, at least one condition in the first and second sets of conditions to operate at least one clamping zone of the first and second sets of clamping zones to apply a different clamping force on the substrate.

86. The method of claim 68 further comprising:

measuring an amount of bow in the substrate;

changing, based on the amount of bow, at least one condition in the first and second sets of conditions to operate at least a first clamping zone of the first and second sets of clamping zones to apply a first clamping force on the substrate based on the amount of bow; and

changing, irrespective of the amount of bow, at least one condition in the first and second sets of conditions to at least a second clamping zone of the first and second sets of clamping zones to apply a second clamping force on the substrate.

87. The method of claim 68 further comprising arranging the plurality of clamping zones concentrically in the substrate support.