

COAXIAL, MULTI-FEED GAS DELIVERY STEM

INCORPORATION BY REFERENCE

[0001] A PCT Request Form is filed concurrently with this specification as part of the present application. Each application that the present application claims benefit of or priority to as identified in the concurrently filed PCT Request Form is incorporated by reference herein in its entirety and for all purposes.

FIELD

[0002] Certain aspects generally pertain to apparatus for semiconductor processing.

BACKGROUND

[0003] Semiconductor manufacturing typically involves one or more processes to deposit and pattern a structure on a wafer. As the complexity and/or non-uniformity of the structure and/or materials on or across the wafer increase, stress applied to the wafer can cause wafer deformation (e.g., bowing, twisting, etc.) impacting various aspects from structure formation to product yield. For example, in three-dimensional NOT-AND logic gate (3D-NAND) structure fabrication, multi-stacked films with thick, high stress carbon-based hard masks, metallization patterns, and substrate trenches can cause significant wafer warpage, leading to issues such as frontside lithographic overlay mismatches, wafer bow beyond chucking limits of an electrostatic chuck, etc.

[0004] The background provided herein is for the purposes of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent that it is described in this background, 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 disclosure.

SUMMARY

[0005] Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. The following, non-limiting implementations are considered part of the disclosure; other implementations will be evident from the entirety of this disclosure and the

accompanying drawings as well.

[0006] Some embodiments provide an apparatus capable of providing one or more gases to a gas distributor (e.g., showerhead, showerhead pedestal, etc.) in distinct or partially mixed states.

[0007] Additional aspects will be set forth in the detailed description which follows, and, in part, will be apparent from the disclosure, or may be learned by practice of the disclosed embodiments and/or the claimed subject matter.

[0008] According to an embodiment, an apparatus for semiconductor processing includes a stem body and a plurality of interior flow paths. The stem body includes a proximal end portion and a distal end portion arranged opposite the proximal end portion along a longitudinal axis of the stem body. The proximal end portion includes a plurality of inlets. Each of the inlets are distinct from one another and configured to receive a corresponding one or more gases. The distal end portion is configured to interface with a gas distributor of a semiconductor processing apparatus. The distal end portion includes a plurality of outlets. At least one of the outlets is distinct from at least another one of the outlets. The plurality of interior flow paths include a first interior flow path and a second interior flow path. Each of the interior flow paths extend between a corresponding inlet among the inlets and at least one corresponding outlet among the outlets such that the interior flow paths are distinct from one another. At least one of the interior flow paths includes one or more structures configured to induce turbulent flow along the longitudinal axis of the stem body in response to a flow of the corresponding one or more gases therealong.

[0009] According to some embodiments, in a section of the stem body, the second interior flow path may encircle the first interior flow path along the longitudinal axis.

[0010] According to some embodiments, wherein, in the section of the stem body, the first interior flow path may be concentrically aligned with the second interior flow path.

[0011] According to some embodiments, the one or more structures may include one or more first structures. Each of the first structures may include a corresponding internal passageway extending along the longitudinal axis of the stem body and defining a respective first portion of the first interior flow path, and a corresponding plurality of first channels extending along the longitudinal axis of the stem body and defining respective first portions of the second interior flow path. The corresponding first channels may be circumferentially spaced apart from one another about the longitudinal axis of the stem body.

[0012] According to some embodiments, each of the corresponding internal passageways may be coaxially aligned with the longitudinal axis of the stem body and fluidically connected with

one another.

[0013] According to some embodiments, the one or more structures may include multiple first structures axially arranged along the longitudinal axis of the stem body. First central axes of the corresponding first channels of one first structure among the multiple first structures may be circumferentially offset from second central axes of the corresponding first channels of another first structure among the multiple first structures.

[0014] According to some embodiments, the first central axes may be incongruent with the second central axes.

[0015] According to some embodiments, the stem body may include a sleeve and a core. The sleeve may include an interior that contacts an exterior of the core. Each of the corresponding internal passageways may extend in a central portion of the core. Each of the corresponding first channels may be formed as a respective first recess in the exterior of the core such that a corresponding first longitudinal passageway is formed, at least in part, by that respective first channel and a corresponding portion of the interior of the sleeve.

[0016] According to some embodiments, the one or more structures may include a second structure. The second structure may include a first interior bore, a second interior bore, and a plurality of second channels. The first interior bore may have a first longitudinal axis. The second interior bore may have a second longitudinal axis offset from the first longitudinal axis. The second interior bore may be fluidically connected with the first interior bore. The plurality of second channels may extend along the longitudinal axis of the stem body and may define respective second portions of the second interior flow path. The second channels may be circumferentially spaced apart from one another about the longitudinal axis of the stem body.

[0017] According to some embodiments, the one or more structures may include three first structures and one second structure.

[0018] According to some embodiments, the second structure may include more second channels than the first structure includes first channels.

[0019] According to some embodiments, each of the first interior bore and the second interior bore may extend in the central portion of the core, the second interior bore may be fluidically connected with at least one of the corresponding internal passageways, and each of the second channels may be formed as a respective second recess in the exterior of the core such that a corresponding second longitudinal passageway is formed, at least in part, by that respective second channel and a corresponding portion of the interior of the sleeve.

[0020] According to some embodiments, at least two directly adjacent second channels among the second channels may be circumferentially spaced apart by a different amount than at least

another two directly adjacent second channels among the second channels.

[0021] According to some embodiments, the second longitudinal passageways may be arranged closer to the proximal end portion than the first longitudinal passageways.

[0022] According to some embodiments, the sleeve may include a first opening and a second opening fluidically connected with the first opening. The first opening may be closer to the proximal end portion than the second opening. The core may include a first end portion and a second end portion. The first end portion may be closer to the proximal end portion than the second end portion. The second end portion may extend out of the second opening and may include the at least one corresponding outlet of the first interior flow path. The second end portion may have a section of reduced cross-sectional area in a plane perpendicular to the longitudinal axis. The at least one corresponding outlet of the second interior flow path may be defined, at least in part, by an exterior of the section of reduced cross-sectional area of the second end portion and a corresponding portion of the interior of the sleeve.

[0023] According to some embodiments, the at least one corresponding outlet of the first interior flow path may be concentrically aligned with the at least one corresponding outlet of the second interior flow path.

[0024] According to some embodiments, the stem body may further include an extension. A first part of the extension may define the proximal end portion. A second part of the extension may interface with each of the sleeve and the core. The extension may include a first interior supply path and a second interior supply path. The first interior supply path may be fluidically connected with at least one of the corresponding internal passageways and may define a portion of the first interior flow path. The second interior supply path may be fluidically connected with at least one of the corresponding first channels and may define a portion of the second interior flow path.

[0025] According to some embodiments, the first end portion may be arranged within the sleeve such that each of an inlet of the first interior bore and inlets of the second channels is axially offset from the first opening. The second part of the extension may include a first body portion, a second body portion, and a third body portion. The first body portion may have a first cross-sectional area in a plane perpendicular to the longitudinal axis. The first body portion may include respective portions of each of the first interior supply path and the second interior supply path. The second body portion may protrude from a central portion of the first body portion and may have a second cross-sectional area in the plane perpendicular to the longitudinal axis. The second cross-sectional area may be smaller than the first cross-sectional area. The second body portion may include a respective portion of the first interior supply path

and an outlet of the second interior supply path. The third body portion may protrude from a central portion of the second body portion and may have a third cross-sectional area in the plane perpendicular to the longitudinal axis. The third cross-sectional area may be smaller than the second cross-sectional area. The third body portion may include a respective portion of the first interior supply path and an outlet of the first interior supply path. The third body portion may extend into the first opening and may interface with the first interior bore to fluidically connect the outlet of the first interior supply path with the inlet of the first interior bore; The second body portion may extend into the first opening and, together with the interior of the sleeve and an exterior of the third body portion, at least partially bound a plenum volume between the outlet of the second interior supply path and the inlets of the second channels. The plenum volume may fluidically connect the outlet of the second interior supply path with the inlets of the second channels.

[0026] According to some embodiments, at least one of a central axis of the first interior supply path and a central axis of the second interior supply path may be offset from the longitudinal axis of the stem body.

[0027] According to some embodiments, each of the central axis of the first interior supply path and the central axis of the second interior supply path may be offset from the longitudinal axis of the stem body.

[0028] According to some embodiments, a proximal end of the core may be welded to the third body portion, and a proximal end of the sleeve may be welded to the first body portion.

[0029] According to some embodiments, the interior flows paths may be fluidically isolated from one another within the stem body.

[0030] According to some embodiments, the apparatus may further include a gas distributor including a first surface and a second surface opposing the first surface. The first surface may include a plurality of inlets. The second surface may include a plurality of gas distribution ports. The stem body may be coupled to the first surface of the gas distributor. The first interior flow path may be fluidically connected with a first group of the gas distribution ports by way of a first outlet among the outlets of the stem body and a first inlet among the inlets of the gas distributor. The second interior flow path may be fluidically connected with a second group of the gas distribution ports by way of a second outlet among the outlets of the stem body and a second inlet among the inlets of the gas distributor. The gas distribution ports of the second group may be distinct from the gas distribution ports of the first group.

[0031] According to some embodiments, the gas distributor may be a showerhead pedestal of the semiconductor processing apparatus. The showerhead pedestal may be configured to

support a substrate at or near its periphery such that a backside of the substrate is substantially exposed to the gas distribution ports.

[0032] According to some embodiments, the apparatus may further include a process chamber configured to support a first portion of the stem body and the gas distributor therein. The process chamber may include an opening through which a second portion of the stem body extends to expose the proximal end portion.

[0033] According to some embodiments, the apparatus may further include a pedestal configured to support a substrate within the process chamber. The process chamber may be configured to support the gas distributor over the pedestal such that the gas distribution ports face the pedestal.

[0034] The foregoing general description and the following detailed description are illustrative and explanatory and are intended to provide further explanation of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] Various embodiments disclosed herein are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings, in which like reference numerals refer to similar elements.

[0036] FIG. 1 schematically illustrates a perspective view of a bowed semiconductor substrate exhibiting asymmetric bowing.

[0037] FIG. 2A schematically illustrates a plan view of a substrate exhibiting asymmetric bowing.

[0038] FIG. 2B schematically illustrates a cross-sectional view of the substrate of FIG. 2A taken along sectional line 2B–2B.

[0039] FIG. 2C schematically illustrates a cross-sectional view of the substrate of FIG. 2A taken along sectional line 2C–2C.

[0040] FIG. 3 is a flowchart of a process to mitigate asymmetric wafer bowing according to some embodiments.

[0041] FIGS. 4A, 4B, 4C, and 4D schematically illustrate various stages of forming a stress compensation layer to mitigate asymmetric wafer bowing according to some embodiments.

[0042] FIG. 5 is a graph illustrating a thickness profile and a stress profile for each of i) a compressive film, ii) a tensile film, and iii) a stress compensation layer combining the compressive film and the tensile film according to some embodiments.

[0043] FIG. 6A is a graph comparing a desired profile and simulated profiles for reactant gas flowing from variously configured gas distributors relative to a backside of a substrate

according to some embodiments.

[0044] FIG. 6B is a graph comparing a desired profile and simulated profiles for dilution gas flowing from variously configured gas distributors relative to a backside of a substrate according to some embodiments.

[0045] FIG. 7 schematically illustrates a perspective view of a gas distributor (e.g., a showerhead pedestal) according to some embodiments.

[0046] FIG. 8 schematically illustrates an orthographic view of a portion of a surface (e.g., a lower surface) of the gas distributor of FIG. 7 according to some embodiments.

[0047] FIGS. 9 and 10 schematically illustrate perspective views of a stem body of the gas distributor of FIG. 7 according to some embodiments.

[0048] FIG. 11 schematically illustrates an exploded perspective view of the stem body of FIG. 9 according to some embodiments.

[0049] FIG. 12 schematically illustrates a cross-sectional view of the stem body according to some embodiments.

[0050] FIGS. 13–16 schematically illustrate cross-sectional views of the stem body of FIG. 12 respectively taken along sectional lines 13–13, 14–14, 15–15, and 16–16 according to some embodiments.

[0051] FIGS. 17–19 schematically illustrate various flow paths within the stem body of FIG. 9 according to some embodiments.

[0052] FIG. 20 schematically illustrates a perspective view of an extension of the stem body of FIG. 9 according to some embodiments.

[0053] FIG. 21 schematically illustrates a cross-sectional view of the extension of FIG. 20 taken along sectional line 21–21 according to some embodiments.

[0054] FIG. 22 schematically illustrates a perspective view of a sleeve of the stem body of FIG. 9 according to some embodiments.

[0055] FIG. 23 schematically illustrates a cross-sectional view of the sleeve of FIG. 22 taken along sectional line 23–23 according to some embodiments.

[0056] FIG. 24 schematically illustrates a perspective view of a core of the stem body of FIG. 9 according to some embodiments.

[0057] FIG. 25 schematically illustrates a cross-sectional view of the core of FIG. 24 taken along sectional line 25–25 according to some embodiments.

[0058] FIG. 26 schematically illustrates an orthographic view of a proximal end of the core of FIG. 24 according to some embodiments.

[0059] FIG. 27 schematically illustrates a substrate processing system configured for backside

wafer deposition according to some embodiments.

[0060] FIG. 28 schematically illustrates a multi-station processing tool configured for backside wafer deposition according to some embodiments.

DETAILED DESCRIPTION OF SOME EMBODIMENTS

[0061] In the following description, numerous specific details are set forth in order to provide a thorough understanding of various embodiments. The disclosed embodiments may be practiced without some or all of these specific details. In other instances, well-known process operations have not been described in detail to not unnecessarily obscure the disclosed embodiments. While the disclosed embodiments will be described in conjunction with specific embodiments, it will be understood that it is not intended to limit the disclosed embodiments.

[0062] In this application, the terms “semiconductor wafer,” “wafer,” “substrate,” “wafer substrate” and “partially fabricated integrated circuit” are used interchangeably. One of ordinary skill in the art would understand that the term “partially fabricated integrated circuit” can refer to a silicon wafer during any of many stages of integrated circuit fabrication thereon. A wafer or substrate used in the semiconductor device industry typically has a diameter of 200 mm, or 300 mm, or 450 mm. In addition to semiconductor wafers, other work pieces that may take advantage of the disclosed embodiments include various articles, such as printed circuit boards, magnetic recording media, magnetic recording sensors, mirrors, optical elements, micro-mechanical devices, and the like.

[0063] Semiconductor fabrication processes involve formation of various structures, many of which may be two-dimensional. As semiconductor device dimensions shrink and devices are scaled to be smaller, the density of features across a semiconductor substrate increases, resulting in layers of material etched and deposited in various ways, including in three dimensions. For example, a 3D-NAND structure is one technology that is becoming increasingly popular due to lower cost and increased memory density compared to other techniques, such as two-dimensional (2D)-NAND structure, and higher reliability in various applications. During the fabrication of a 3D-NAND structure, wafer bow can change drastically. For example, deposition of thick hard mask materials and etching of trenches along a wafer surface in fabricating a 3D-NAND structure can cause wafer bowing. As layers of films are stacked on top of each other during fabrication, more stress is introduced to the semiconductor wafer which can cause bowing. Moreover, stress fields along different axes of the wafer may become increasingly inhomogeneous, leading to multimodal bow shapes.

[0064] Bowing can be measured using an optical technique. Wafer bowing can be measured

or evaluated by obtaining a wafer map or stress map. Bowing can be quantified using a bow value and/or a warpage value as described herein. In general, a “wafer bow value” measures the deviation of the center point of a median surface of a free, un-clamped wafer from the median surface to a reference plane, which is defined by three corners of an equilateral triangle having a base a specified amount less than the nominal diameter of the wafer, according to the American Society for Testing and Materials (ASTM) F534 standard. A “wafer warp value” is the difference between the maximum and the minimum distances of the median surface of a free, un-clamped wafer from the reference plane, according to the ASTM F657 and ASTM F1390 standards. It is noted, however, that the warpage value can be expressed along one or more axes – for example, an asymmetrically warped wafer may have an x-axis warpage and/or a y-axis warpage. Further, “wafer flatness” is a measure of the deviation of the front surface of a wafer, expressed in total indicator reading or maximum focal plane deviation, relative to a specified reference plane when the back surface of the wafer is ideally flat, according to the ASTM F1530 standard.

[0065] In a bow-shaped wafer, the lowest point is the center of the wafer and the highest point is the edge of the wafer. In a dome-shaped wafer, the lowest point is the edge of the wafer and the highest point is the center of the wafer. Bow-shaped and dome-shaped wafers have symmetrical or largely symmetrical bowing. Wafers can also have asymmetric bowing. In asymmetric bowing, warpage is measured along an x-axis and a y-axis. An asymmetrically bowed wafer has different values for the x-axis warpage and y-axis warpage. In some cases, an asymmetrically bowed wafer has a negative x-axis warpage and a positive y-axis warpage. In some cases, an asymmetrically bowed wafer has a positive x-axis warpage and a negative y-axis warpage. In some cases, an asymmetrically bowed wafer has both a positive x-axis warpage and a positive y-axis warpage, but the warpage values are different. In some instances, an asymmetrically bowed wafer has both a negative x-axis warpage and a negative y-axis warpage, but the warpage values are different. One example of an asymmetrically bowed wafer is a saddle-shaped wafer. For a saddle-shaped wafer, in one example, the warpage on the x-axis may be +200 μm and the warpage on the y-axis may be -200 μm . Saddle-shaped wafers have two opposing edges of the wafer that are curved upward while another two opposing edges of the wafer are curved downward. As used herein, warpage can refer to any deviation from planarity exhibited by a wafer, where a bow-shaped wafer, dome-shaped wafer, and saddle-shaped wafer are examples of different types of substrate warpage.

[0066] Bowing can cause problems with subsequent processing, such as during lithography, as etching can be uneven if the semiconductor substrate is warped. High bowing can be caused

by deposition of a thick, high-stress carbon hard mask layer(s). Additionally, due to multi-stacked films and the presence of thick, high-stress carbon-based hard masks used in such fabrication processes, etching can cause some asymmetric warpage and deposition processes can introduce significant wafer warpage of up to a variation between $-1300\text{ }\mu\text{m}$ to $+1300\text{ }\mu\text{m}$ bow. For example, an ashable hard mask may have a stress value of up to -1000 MPa and have a bow value of up to $-1000\text{ }\mu\text{m}$. In some cases, a high-aspect ratio slit etch and metal fill (e.g., tungsten fill) can induce large anisotropic stress on the semiconductor substrate.

[0067] Addressing such wafer warpage can be a challenge as subsequent or downstream processing may be affected by a wafer warpage exceeding, for example, about $\pm 150\text{ }\mu\text{m}$, about $\pm 200\text{ }\mu\text{m}$, about $\pm 300\text{ }\mu\text{m}$, or about $\pm 500\text{ }\mu\text{m}$. It, however, is recognized that as processes become more sensitive to wafer topology, lesser degrees of wafer warpage may need to be addressed. One example issue is that mechanical wafer handling may be affected due to wafer warpage, where wafers that are not flat may not be gripped or held effectively by a wafer robot or wafer handling mechanism. Additionally, wafer warpage may contribute to process non-uniformity, where downstream etch, deposition, or clean operations may be adversely affected due to processing non-uniformities across a surface of the wafer. For instance, wafer warpage may lead to poor thermal contact, which can cause non-uniform heating of a wafer that, in turn, can lead to non-uniform processing of the wafer. In some instances, processing of highly warped wafers may cause further warping. For example, etching of a trench in one direction can cause warping in asymmetric bowing due to asymmetric stress on the wafer. In addition, lithography operations may be adversely affected by wafer warpage as precise patterns are unable to be formed. When wafers are used in subsequent processing that involve chucking of the wafer to an electrostatic chuck, highly warped wafers may not be able to be processed in some tools. Many electrostatic chucks have a “chucking limit,” which is defined as the maximum warpage tolerated before the wafer cannot be effectively chucked. For example, some electrostatic chucks have a chucking limit of about $\pm 300\text{ }\mu\text{m}$. Warped wafers that exceed the chucking limit may not be processed in such instances.

[0068] FIG. 1 schematically illustrates a perspective view of a bowed semiconductor substrate exhibiting asymmetric bowing.

[0069] Referring to FIG. 1, substrate **101** is shown relative to a three-dimensional coordinate system having reference plane **103** parallel to a plane defined by the x-axis direction and the y-axis direction. In this manner, an extent of deformation (e.g., warpage) of substrate **101** from reference plane **103** is indicated along the u axis-direction. Accordingly, substrate **101** is shown as being asymmetrically bowed. In other words, an extent of the bowing of substrate

101 along the x-axis direction is different from an extent of the bowing of substrate **101** along the y-axis direction. For instance, warpage in the x-axis direction reaches a first positive value and warpage in the y-axis direction reaches a second negative value, a magnitude of the second negative value being greater than a magnitude of the first positive value. Such deformation of substrate **101** may be referred to as “saddle-shaped” bowing of substrate **101**. As used herein, warpage refers to any deviation of a median surface of substrate **101** from reference plane **103**, and, thereby, from planarity.

[0070] As 3D-NAND structures continue to scale up and high-aspect ratio features become increasingly more common, new challenges are emerging related to localized stress and inter-die stress variations on semiconductor substrates. Localized stress and inter-die stress variations may lead to block-bending, cell cross-talk, cell loss, and/or cell misalignments. Localized stress refers to stress changes that occur within a wafer in a non-uniform manner. Poorly compensated/corrected localized stress may lead to localized wafer topology changes, which in turn may lead to poor alignment during lithography. Such poor alignment is typically viewed in terms of in-plane distortion (IPD), which is a quantification of the vector displacement of on-wafer alignment marks from their expected positions due to wafer topology. High IPD during lithography may lead to undesirable changes in critical dimensions or any other feature that is defined in a lithographic step, and so the foregoing phenomena of block-blending, cell cross-talk, cell loss, and/or cell misalignments can arise due to lithographic errors.

[0071] FIGS. 2A–2C schematically illustrate various views of a substrate exhibiting asymmetric bowing. For instance, FIG. 2A schematically illustrates a plan view of substrate **201**, whereas FIGS. 2B and 2C schematically illustrate cross-sectional views of substrate **201** taken along sectional lines 2B–2B and 2C–2C, respectively. As seen in FIG. 2A, substrate **201** may include various features (e.g., metallization pattern **203**) formed on frontside **205** that cause, at least in part, substrate **201** to asymmetrically bow. For illustrative convenience, feature formations on frontside **205** of substrate **201** are not shown in FIGS. 2B and 2C. As can be appreciated from FIGS. 2B and 2C, substrate **201** exhibits parabolic bowing along the x-axis direction and anti-parabolic bowing along the y-axis direction, the combination of which can yield saddle-shaped bowing similar to the saddle-shaped bowing of substrate **101** in FIG. 1.

[0072] Various techniques may be employed to address the bowing of a substrate, such as substrate **201**. For instance, one or more stress compensation layers may be formed on a backside of a semiconductor substrate, such as backside **207**. The utilization of backside stress

compensation layers has typically been limited to mitigating monotonic global wafer warpage. In other words, techniques to address the bowing of semiconductor substrates are usually limited to addressing axially symmetric or multi-axially symmetric bow profiles. In some instances, asymmetric bowing may be addressed through the formation of backside stress compensation layers using mask or precursor zoning techniques during layer formation. For instance, localized stress modulation may be achieved through the delivery of precursor material to certain areas or regions of an asymmetrically bowed substrate using, for instance, a carrier ring mask. In other instances, localized stress modulation may be achieved using precursor zoning employing multiple plenums to control delivery of gas to different locations. However, such techniques have yielded limited success due, in part, to high IPD overlay and issues associated with chucking a bowed substrate. Such issues may be the result of sharp transitions in film stress between zones and the difficulty in designing a zone layout that minimizes local topography variation.

[0073] Accordingly, one or more embodiments seek to provide methods and apparatuses for mitigating asymmetric bowing of a substrate via backside deposition. Precursor control from a gas distributor (e.g., a showerhead, showerhead pedestal, etc.) may provide a desired thickness profile in one or more films deposited on a backside of a substrate. The one or more deposited films may be utilized to collectively form a stress compensation layer. A stress profile of the stress compensation layer may be characterized by a polynomial function. In this manner, the stress compensation layer may mitigate or even resolve localized stress in an asymmetrically bowed substrate. In some implementations, the stress compensation layer may be formed through a film stacking approach, which deposits multiple films having different thickness profiles. In some implementations, a combination of a compressive film having a non-linear thickness profile and a tensile film having a different non-linear thickness profile may be deposited on a backside of a bowed substrate. For instance, the compressive film may have a first parabolic-shaped profile and the tensile film may have a second parabolic-shaped profile opening in a direction opposite the first parabolic-shaped profile. In this manner, the compressive film and the tensile film can be collectively utilized to form a stress compensation layer. In some instances, the stress compensation layer may be flat or substantially flat. Such a film stacking technique via backside deposition may be utilized to minimize (or at least reduce) IPD overlay issues without impacting the ability to chuck the substrate.

[0074] Thickness tuning of the one or more films in a stress compensation layer may be achieved by controlling precursor and dilution gas concentration proximate (or adjacent) to a substrate during one or more deposition operations. According to various embodiments,

precursor and dilution gas concentration adjacent to the substrate may be controlled by design features in a gas distributor, which may include a coaxial, multi-feed gas delivery stem. Such design features may influence flow dynamics of the precursor and dilution gases from the gas distributor. In an embodiment, the gas distributor may be divided into multiple gas distribution groups (or zones). For example, one or more precursor gases may be delivered to (and, thereby, from) one or more first zones, one or more precursor gases and one or more one or more dilution gases may be delivered to (and, thereby, from) one or more second zones, and one or more precursor gases and one or more one or more dilution gases may be delivered to (and, thereby, from) one or more third zones. In some instances, gas output from (or a gas flow profile across) one zone may be uniform (or substantially uniform) and gas output from one or more other zones may be irregular, e.g., exhibit a gradient, such as a non-linear gradient increasing with increasing distance from the one zone, such as a parabolic gradient increasing with increasing distance from the one zone. It is note that the gradient may be with respect to one or more different gases flowed in the one or more other zones. The term “uniform,” as used herein with respect to gas flows and gas flow profiles, refers to a gas flow or gas flow profile that is substantially uniform or similar; such gas flows or gas flow profiles may potentially include minor perturbations or deviations due to various localized effects, but would still be recognizable as generally uniform. To this end, the various gas flow profiles referred to herein may be considered an effect of the structure(s) of the gas distributor, and, thereby, understood as occurring under identical inlet/outlet boundary conditions, e.g., pressure, temperature, etc. In some cases, gas output from the one or more other zones may exhibit a stepped gradient increasing with increasing distance from the one zone or any other suitable gas output profile.

[0075] According to some embodiments, a combined gas flow profile of all the gas distribution ports may exhibit mirror symmetry about an axis, but not exhibit 3-fold or higher radial symmetry. Such multizone flow control can be utilized to modulate the concentration of precursor and dilution gas adjacent to a substrate during layer formation. It is also contemplated that one or more primary zones may include one or more sub-zones and the one or more sub-zones may, in some implementations, include one or more sub-portions to further tailor the concentration of precursor and dilution gas (or flow dynamics) adjacent to the substrate, such as the flow dynamics in proximity to an edge of the substrate. This may be achieved via different gas distribution port patterns (e.g., positions, densities, port sizes, etc.) between a primary zone, a sub-zone, and/or a sub-portion of a sub-zone. In some cases, additional and/or alternative control (e.g., smoothing of the concentration of precursor and

dilution gas (or flow dynamics associated therewith)) within and/or between zones, sub-zones, and/or sub-portions of sub-zones) may be achieved via interlaced, alternating, or otherwise integrated patterns of two or more types of gas distribution ports, such as gas distribution ports configured to flow precursor and gas distribution ports configured to flow dilution gas. In some cases, different gas distribution flow paths (e.g., sizes, amounts, flow conductance, etc.) supplying one or more precursor gases or one or more dilution gases to different zones, sub-zones, and/or sub-portions of sub-zones may be additionally or alternatively utilized to tailor the concentration of precursor and dilution gas (or flow dynamics) adjacent to the substrate. It is also noted that the aforementioned coaxial, multi-feed gas delivery stem may be utilized to provide the precursor and dilution gases to the gas distributor in one or more distinct or partially mixed states.

[0076] FIG. 3 is a flowchart of a process to mitigate asymmetric wafer bowing according to some embodiments. FIGS. 4A, 4B, 4C, and 4D schematically illustrate various stages of forming a stress compensation layer to mitigate asymmetric wafer bowing according to some embodiments. Process 300 may be performed in a different order and/or with different, fewer, or additional operations. The operations of process 300 will be described in association with the various stages of forming a stress compensation layer shown in FIGS. 4A to 4D. Further, the operations of process 300 may be performed using an apparatus for film deposition, such as an apparatus described in association with one or more of FIGS. 7–28. In some cases, the operations of process 300 may be implemented, at least in part, according to software stored in one or more non-transitory computer readable media.

[0077] At block 301, a substrate exhibiting asymmetric bowing may be caused, at least in part, to be loaded into a deposition apparatus, such as an apparatus configured to deposit material on a backside of the substrate. A stress profile acting on the substrate may include one or more compressive regions and/or one or more tensile regions non-uniformly applied to the substrate. In general, tensile stress applied across a substrate induces warpage having positive values and causes, at least in part, concave bending of the substrate. Compressive stress applied across a substrate induces warpage having negative values and causes, at least in part, convex bending of the substrate. The combination of various tensile and compressive stresses across the substrate may result in the substrate including a surface (e.g., median surface) deviating from a reference plane representing an otherwise planar configuration. In some instances, warpage of the substrate may exceed $\pm 300\text{ }\mu\text{m}$. Further, the asymmetric bowing may result in a saddle-shaped or reversed saddle-shaped substrate.

[0078] The substrate may be a silicon wafer, such as a 200-mm wafer, a 300-mm wafer, a 450-

mm wafer, or the like, including one or more layers of material, such as dielectric, conducting, and/or semiconducting materials, deposited on a frontside of the substrate. Some of the one or more layers may be patterned. Non-limiting examples of layers include dielectric layers and conductive layers, such as silicon oxides, silicon nitrides, silicon carbides, metal oxides, metal nitrides, metal carbides, and metal layers. In some instances, the substrate itself may be patterned. For example, the substrate may include a 3D-NAND structure having one or more trenches formed (e.g., etched) in the substrate. Accordingly, the one or more compressive regions and the one or more tensile regions of the stress profile may be attributable to, for instance, the one or more layers of materials on the substrate, the one or more patterns in the one or more layers, the one or more trenches in the substrate, etc.

[0079] The substrate may exhibit warpage, such as warpage of about $\pm 1000\ \mu\text{m}$. In some instances, the substrate may have warpage exceeding about $\pm 300\ \mu\text{m}$. In some cases, the substrate has warpage greater than about $\pm 300\ \mu\text{m}$ and less than about $\pm 1000\ \mu\text{m}$. The warpage may occur at one or more regions of the substrate. To this end, the warpage may have different values (or profiles) along an x-axis direction and a y-axis direction. The warpage may be a result of anisotropic stress distribution in the substrate.

[0080] As used herein, tensile regions create tensile stresses that induce warpage having positive values. Tensile regions cause concave bending of a substrate. As used herein, compressive regions create compressive stresses that induce warpage having negative values. Compressive regions cause convex bending of a substrate. The one or more compressive regions and the one or more tensile regions may be attributable to, for instance, the one or more layers of materials on the substrate, the one or more patterns in the one or more layers, the one or more trenches in the substrate, etc.

[0081] In some implementations, a center of the substrate has compressive stress and at least two opposing edges of the substrate have tensile stress. In some cases, a center of the substrate has tensile stress and at least two opposing edges of the substrate have compressive stress. A stress profile in the x-axis direction of the substrate may be described by a parabolic or other non-linear function. A stress profile in the y-axis direction of the substrate may be described by a parabolic or other non-linear function. To this end, the stress profile in the x-axis direction may be described by a polynomial function and the stress profile in the y-axis direction may be described by a polynomial function.

[0082] According to some embodiments, the substrate is caused, at least in part, to be provided in a process chamber (e.g., chamber 2703 of FIG. 27) for performing a deposition operation. The process chamber may be configured for backside and/or frontside deposition. In some

implementations, backside deposition may be achieved by delivering process gases to a backside of the substrate from a bottom showerhead, e.g., a showerhead pedestal, of the process chamber. In some implementations, the backside of the substrate is not patterned. Showerheads generally described herein refer to showerhead pedestals for delivering gases to a backside of the substrate.

[0083] FIG. 4A schematically illustrates a cross-sectional view of a substrate exhibiting asymmetric bowing. Although not visibly shown, substrate **401** is bowed. Frontside **401a** of substrate **401** may be patterned with structures leading to anisotropic stress distribution in substrate **401**. The anisotropic stress distribution may be characterized by a polynomial function, such as a parabolic function in one or both of the x-axis and y-axis directions, where the x-axis and y-axis define a reference plane of substrate **401**. Substrate **401** may be asymmetrically bowed. For example, substrate **401** may exhibit saddle-shaped bowing. In some cases, substrate **401** may have warpage greater than or equal to about +300 μm or less than or equal to about -300 μm in one or both of the x-axis and y-axis directions. Substrate **401** may be caused, at least in part, to be provided in a process chamber for deposition, such as a process chamber for backside deposition.

[0084] Adverting back to FIG. 3, at block **303**, a first film is caused, at least in part, to be deposited on backside **401b** of substrate **401** utilizing a first gas flow configuration from a showerhead pedestal. The first film is caused, at least in part, to have a first non-linear thickness profile on backside **401b** of substrate **401**.

[0085] According to one embodiment, the first film is a compressive film, which is a thin film having an intrinsic compressive stress. The compressive film may have an intrinsic compressive stress, such as a negative stress value of up to -4000 MPa. A thickness profile is presented along an axial direction (e.g., x-axis or y-axis direction) of the film. A non-linear thickness profile is characterized by any deviation from linearity of the film along the axial direction. The non-linear thickness profile may be characterized by a parabolic function or other polynomial function. For instance, the non-linear thickness profile may be a first parabolic-shaped profile that opens upwards or downwards. Where the first parabolic-shaped profile opens upwards, the compressive film is thicker at the edges of substrate **401** and tapers at the center of substrate **401**. Where the first parabolic-shaped profile opens downwards, the compressive film is thicker at the center of the substrate **401** and tapers at the edges. Depending on the warpage of substrate **401**, the compressive film may have a non-linear thickness profile in one or both of the x-axis and y-axis directions.

[0086] Depositing a compressive film according to a non-linear thickness profile may occur

by controlling precursor and/or dilution gas concentration from a showerhead pedestal. The precursor and/or dilution gas concentration may be controlled to vary across backside **401b** of substrate **401**. For instance, thickness control may be achieved by controlling precursor and/or dilution gas concentration adjacent to backside **401b** of substrate **401** during deposition. More precursor for depositing a compressive film is flowed in the compressive region(s). Less or no precursor for depositing the compressive film is flowed in the tensile region(s). Controlling precursor concentration to vary across backside **401b** of substrate **401** may occur by influencing flow dynamics from the showerhead pedestal. Precursor and/or dilution gas concentration may vary along one or both of an x-axis and y-axis directions of substrate **401**.

[0087] In some implementations, a compressive film may be a compressive silicon oxide, a compressive silicon nitride, a compressive silicon, or a compressive carbon film, but embodiments are not limited thereto. For instance, in some implementations, the compressive film is a compressive silicon oxide film or a compressive silicon nitride film. A selection of precursor gas, dilution gas, and process conditions can be used to tune the stress of the compressive film. In some implementations, the compressive film is deposited on backside **401b** of substrate **401** using any suitable deposition technique, such as plasma enhanced chemical vapor deposition (PECVD), chemical vapor deposition (CVD), plasma enhanced atomic layer deposition (PEALD), or atomic layer deposition (ALD). For example, the compressive film may be caused, at least in part, to be deposited using PECVD.

[0088] As used herein, “silicon oxide” includes chemical compounds including silicon and oxygen atoms, including any and all stoichiometric possibilities for Si_xO_y , including integer values of x and y and non-integer values of x and y. Further, “silicon nitride” is referred to herein as including any and all stoichiometric possibilities for Si_xN_y , including integer values of x and y and non-integer values of x and y; for example, a ratio X:Y may be 3:4.

[0089] In some embodiments, a compressive silicon oxide film may be deposited using a mixture of a silicon-containing precursor and an oxygen-containing reactant. Examples of silicon-containing precursors include but are not limited to silanes and tetraethyl orthosilicate (TEOS). Examples of oxygen-containing reactants include but are not limited to oxygen and nitrous oxide. In PECVD, the silicon-containing precursor may react with the oxygen-containing reactant exposed to plasma to form the compressive silicon oxide film. An inert gas, such as helium, may be present.

[0090] According to some implementations, a compressive silicon nitride film may be deposited using a mixture of a silicon-containing precursor and a nitrogen-containing reactant. Examples of silicon-containing precursors include but are not limited to silanes and TEOS.

Examples of nitrogen-containing reactants include but are not limited to nitrogen and ammonia. In PECVD, the silicon-containing precursor may react with the nitrogen-containing reactant exposed to plasma to form the compressive silicon nitride film. An inert gas, such as helium, may be present.

[0091] The selection of a silicon-containing precursor and reactants, as well as the plasma type (dual or single frequency) and process conditions may affect the stress of the film being deposited. In some implementations, a flow rate of the silicon-containing precursor relative to other gases flowed during deposition may tune the stress. For example, in deposition of compressive silicon nitride, increase in silane flow may decrease stress, making what would be a compressive silicon nitride film less compressive. Thus, in some implementations, increase in silane flow causes the deposited film to be less compressive, and, in some implementations, substrate temperature may be tuned to modulate stress in the compressive film. For example, higher temperatures may be used to achieve higher stress or increase a stability of the film being deposited. In some implementations, substrate temperature for deposition on backside **401b** of substrate **401** is greater than or equal to about 200°C and less than or equal to 650°C.

[0092] According to some embodiments, a compressive film may be used to compensate the one or more compressive regions of substrate **401**. In some implementations, the thickness of the compressive film may vary based on location on substrate **401**. For instance, the thickness of the compressive film at any given location may be greater than or equal to 0 nm and less than or equal to about 2000 nm. To this end, an average thickness of the compressive film may be about 1000 nm, but embodiments are not limited thereto. A thickness of the compressive film can affect wafer bow of the compressive film to compensate asymmetric bowing in substrate **401**. Accordingly, a non-linear thickness profile in the compressive film achieves a desired wafer bow that compensates the one or more compressive regions of substrate **401**.

[0093] FIG. 4B schematically illustrates a cross-sectional view of compressive film **403** having a parabolic thickness profile deposited on backside **401b** of substrate **401**. Compressive film **403** may be caused, at least in part, to be deposited by PECVD. Compressive film **403** may be a compressive silicon oxide film, a compressive silicon nitride film, a compressive silicon film, a compressive carbon film, or the like. Compressive film **403** may be thicker at a center of substrate **401** than at opposite edges of substrate **401**. Although compressive film **403** is shown having a parabolic thickness profile, the thickness profile may match or substantially match a polynomial function, such as a second order or third order polynomial function. The parabolic thickness profile of compressive film **403** opens downwards. The parabolic thickness profile of compressive film **403** is depicted along an x-axis or y-axis direction.

[0094] According to some embodiments, the first film may be a tensile film having a second non-linear thickness profile on backside **401b** of substrate **401**. A tensile film refers to a thin film having an intrinsic tensile stress. The tensile film may have an intrinsic tensile stress, such as a positive stress value of up to +4000 MPa. The non-linear thickness profile may be characterized by a parabolic function or other polynomial function. Depending on the warpage in substrate **401**, the tensile film may have a non-linear thickness profile in one or both of the x-axis and y-axis directions. In some implementations, the non-linear thickness profile may be a second parabolic-shaped profile that opens downwards or upwards. In some implementations, the second parabolic-shaped profile opens in a direction opposite the first parabolic-shaped profile.

[0095] Depositing a tensile film according to a non-linear thickness profile may occur by controlling precursor and/or dilution gas concentration from a showerhead pedestal. The precursor and/or dilution gas concentration may be controlled to vary across backside **401b** of substrate **401**. For instance, thickness control may be achieved by controlling precursor and/or dilution gas concentration adjacent to backside **401b** of substrate **401** during deposition. More precursor for depositing the tensile film may be flowed in the tensile region(s), and less or no precursor for depositing the tensile film may be flowed in the compressive region(s). It is noted that controlling the precursor and/or dilution gas concentration to vary across backside **401b** of substrate **401** may occur by influencing flow dynamics from the showerhead pedestal. To this end, the precursor and/or dilution gas concentration may vary along one or both of an x-axis and y-axis directions of the substrate **401**.

[0096] In some implementations, the tensile film may be a tensile silicon oxide film, a tensile silicon nitride film, a tensile silicon film, a tensile carbon film, or the like. For instance, the tensile film may be a tensile silicon oxide film or a tensile silicon nitride film. Selection of precursors, dilution gas, and process conditions can be used to tune the stress of the tensile film. In some implementations, the tensile film is deposited on backside **401b** of substrate **401** using any suitable deposition technique, such as PECVD, CVD, PEALD, or ALD. For example, the tensile film may be caused, at least in part, to be deposited using PECVD.

[0097] In some implementations, a tensile silicon oxide film may be deposited using a mixture of a silicon-containing precursor and an oxygen-containing reactant. In PECVD, the silicon-containing precursor may react with the oxygen-containing reactant exposed to plasma to form the tensile silicon oxide film. An inert gas, such as helium, may be present.

[0098] A tensile silicon nitride film may be deposited, in some embodiments, using a mixture of a silicon-containing precursor and a nitrogen-containing reactant. In PECVD, the silicon-

containing precursor may react with the nitrogen-containing reactant exposed to plasma to form the tensile silicon nitride film. An inert gas, such as helium, may be present.

[0099] Selection of a silicon-containing precursor and reactants, as well as the plasma type (dual or single frequency) and process conditions may affect the stress of the film being deposited. In some implementations, a flow rate of the silicon-containing precursor relative to other gases flowed during deposition may tune the stress. In some implementations, substrate temperature may be tuned to modulate stress in the tensile film. For example, higher temperatures may be used to achieve higher stress or increase a stability of the film being deposited. In some implementations, substrate temperature for deposition on backside **401b** of substrate **401** is greater than or equal to about 200°C and less than or equal to 650°C. Embodiments, however, are not limited thereto.

[0100] A tensile film may be used to compensate the one or more tensile regions of substrate **401**. In some implementations, the thickness of the tensile film may vary based on location on substrate **401**. For instance, the thickness of the tensile film at any given location may be greater than or equal to 0 nm and less than or equal to about 2000 nm. To this end, an average thickness of the tensile film may be about 1000 nm, but embodiments are not limited thereto. A thickness of the tensile film can affect wafer bow of the tensile film to compensate asymmetric bowing in substrate **401**. Accordingly, a non-linear thickness profile in the tensile film achieves a desired wafer bow that compensates the one or more tensile regions of substrate **401**.

[0101] FIG. 4C schematically illustrates a cross-sectional view of tensile film **405** having a parabolic thickness profile deposited on backside **401b** of substrate **401**. Tensile film **405** may be deposited by PECVD. Tensile film **405** may be a tensile silicon oxide film, a tensile silicon nitride film, a tensile silicon film, a tensile carbon film, or the like. In some cases, tensile film **405** may be thicker at opposite edges of substrate **401** than at a center of substrate **401**. Although tensile film **405** is shown having a parabolic thickness profile, the thickness profile may match or substantially match a polynomial function, such as a second order or third order polynomial function. The parabolic thickness profile of tensile film **405** opens upwards. The parabolic thickness profile of tensile film **405** is depicted along an x-axis or y-axis direction.

[0102] Adverting back to FIG. 3, at block **305**, substrate **401** including the first film formed on backside **401b** may be optionally caused, at least in part, to be rotated by a predetermined amount before formation of another film on the first film. For instance, substrate **401** may be caused, at least in part, to be rotated greater than about 0° and less than about 180°, such as greater than about 30° and less than about 150°, e.g., greater than about 60° and less than about

120°, for instance, greater than about 80° and less than about 100°. In one embodiment, the substrate **401** may be caused, at least in part, to be rotated by or about 90°. It is noted, however, that any other suitable rotation may be utilized.

[0103] According to some embodiments, rotation of substrate **401** may be achieved manually or via one or more automated methods. For instance, substrate **401** may be removed from a processing chamber, rotated using an external aligner, and loaded back into the processing chamber. In some implementations, substrate **401** may be rotated in a processing chamber via rotation of a support structure, e.g., a susceptor, a showerhead pedestal, etc. It is also contemplated that substrate **401** may be rotated within a processing chamber via a spindex, spider forks, or any other suitable wafer handling robot.

[0104] At block **307**, a second film is caused, at least in part, to be formed on the first film utilizing a second gas flow configuration different from the first gas flow configuration. In some implementations, the second gas flow configuration may be opposite of the first gas flow configuration, as will become more apparent below. It is noted, however, that the first gas flow configuration may include one or more process gases being flowed in at least one first zone of a showerhead pedestal, and one or more process gases and one or more dilution gases being flowed in second and third zones of the showerhead pedestal that flank the first zone. In this manner, the second gas flow configuration may include one or more dilution gases being flowed in the first zone of the showerhead pedestal, and one or more process gases and one or more dilution gases being flowed in the second and third zones of the showerhead pedestal. It is noted, however, that the one or more process gases flowed in the second and third zones during the second gas flow configuration may be flowed from those gas distribution ports having flowed the one or more dilution gases during the first gas flow configuration, and the one or more dilution gases flowed in the second and third zones during the second gas flow configuration may be flowed from those gas distribution ports having flowed the one or more process gases during the first gas flow configuration. Embodiments, however, are not limited thereto, and other and/or additional gas flow configurations are contemplated.

[0105] In some implementations, the second film may be configured to apply a second stress profile on substrate **401** that is different from a first stress profile applied by the first film. As such, deposition of the compressive film and the tensile film may occur interchangeably. That is, the compressive film may be deposited first followed by the tensile film, or the tensile film may be deposited first followed by the compressive film. In either case, the compressive film and the tensile film may be stacked and together achieve a flat or substantially flat surface forming a stress compensation layer. This flatness may result from the compressive film

having a first non-linear thickness profile different from the tensile film having a second non-linear thickness profile. As a result, a stress compensation layer is formed on backside **401b** of substrate **401** that is flat or substantially flat. In general, a stress compensation layer refers to the one or more films deposited on backside **401b** of substrate **401** to correct or compensate wafer bowing in substrate **401**. As used herein, the phrase “substantially flat” refers to wafer bowing or deviations from a flat reference plane that is less than about 100 μm . Having a flat or substantially flat stress compensation layer reduces IPD, where low IPD reduces overlay impact, ensures proper wafer chucking, and avoids defocusing.

[0106] According to various embodiments, a stress compensation layer is formed by stacking multiple films, e.g., the compressive film and the tensile film, with the stress compensation layer having a non-linear stress profile. The non-linear stress profile of the stress compensation layer may be largely characterized by a polynomial function, such as a parabolic function. In some implementations, additional films or layers may be stacked on the compressive film and tensile film for achieving a desired stress profile in the stress compensation layer. In some implementations, the stress compensation layer is removed. For instance, the stress compensation layer may be removed in further downstream processing operations.

[0107] FIG. 4D schematically illustrates a side view of stress compensation layer **407** formed on backside **401b** of substrate **401**. Stress compensation layer **407** includes compressive film **403** and tensile film **405** stacked on one another. By stacking compressive film **403** and tensile film **405**, stress compensation layer **407** achieves a flat or substantially flat surface **407a**. At least because compressive film **403** and tensile film **405** open in opposite directions, combining the thickness profiles of compressive film **403** and tensile film **405** forms a flat or substantially flat profile. Different regions of stress compensation layer **407** have different stress values to locally modulate stress. The stress variation in stress compensation layer **407** may be characterized by a polynomial function, such as a parabolic function. In various embodiments, stress compensation layer **407** mitigates asymmetric bowing in substrate **401**. Prior to depositing stress compensation layer **407**, substrate **401** may have warpage greater than or equal to about +300 μm or less than or equal to about -300 μm in one or both of the x-axis and y-axis directions. After depositing stress compensation layer **407**, substrate **401** may have warpage between about -300 μm and about +300 μm in both the x-axis and the y-axis directions. In some implementations, substrate **401** may have warpage between about -100 μm and about +100 μm in both the x-axis and the y-axis directions after depositing stress compensation layer **407**. It, however, is also contemplated that formation of stress compensation layer **407** on backside **401b** of substrate **401** may eliminate (or substantially

eliminate) warpage in one or more of the x-axis and the y-axis directions, e.g., reduce warpage in one or more of the x-axis and the y-axis directions to or about 0 μm .

[0108] FIG. 5 is a graph illustrating a thickness profile and a stress profile for each of i) a compressive film, ii) a tensile film, and iii) a stress compensation layer combining the compressive film and the tensile film according to some embodiments.

[0109] As seen in FIG. 5, an upper portion of the graph provides a thickness profile as a function of position along the x-axis direction of a substrate. A lower portion of the graph provides a stress profile as a function of position along the x-axis direction of the substrate. Values in the stress profile are product values of stress multiplied by film thickness. The product value of stress multiplied by film thickness correlates with wafer bowing.

[0110] With respect to thickness profiles, first thickness profile **510** of a highly compressive film is depicted having a first parabolic-shaped curve. The thickness changes as a polynomial function such that the thickness in first thickness profile **510** increases parabolically towards the center of the substrate and parabolically decreases towards the edges of the substrate. Second thickness profile **520** of a highly tensile film is depicted as a second parabolic-shaped curve opening in a direction opposite the first parabolic-shaped curve. For instance, the thickness changes as a polynomial function such that the thickness in second thickness profile **520** increases parabolically towards the edges of the substrate and decreases parabolically towards the center of the substrate. A combination of the highly compressive film and the highly tensile film yield third thickness profile **530**, which is flat or uniform across the x-axis direction of the substrate.

[0111] With continued reference to FIG. 5, first stress profile **515** of the highly compressive film is depicted as a third parabolic-shaped curve. As the thickness of the highly compressive film parabolically increases towards the center of the substrate, the stress parabolically decreases, and, thereby, becomes more negative. As the thickness of the highly compressive film parabolically decreases at the edges of the substrate, the stress parabolically becomes less negative and crosses the neutral axis. Second stress profile **525** of the highly tensile film is depicted as a fourth parabolic-shaped curve. As the thickness of the highly tensile film parabolically increases towards the edges of the substrate, the stress parabolically increases. As the thickness of the highly tensile film parabolically decreases towards the center of the substrate, the stress parabolically decreases and reaches the neutral axis. Third stress profile **535** is a result, e.g., total stress, applied by the combination of the highly compressive film and the highly tensile film. Towards the edges of the substrate, the stress of third stress profile **535** parabolically increases, whereas towards the center of the substrate, the stress parabolically

becomes more negative.

[0112] According to various embodiments, a thickness profile of a compressive or tensile film is modulated by controlling a concentration of precursor and dilution gas adjacent to a substrate during material deposition. This concentration of precursor and dilution gas may be controlled by varying how much precursor and dilution gas is flowed from a gas distributor, such as a showerhead or showerhead pedestal, along at least one of the x-axis and y-axis directions. Structural components of the gas distributor may be configured to vary precursor and/or dilution gas distribution therefrom.

[0113] For descriptive and illustrative convenience, various embodiments will be described in association with showerhead pedestal implementations configured to modulate precursor and dilution gas distribution adjacent to a backside of a substrate. It will be appreciated, however, that some embodiments are equally applicable to showerhead implementations, as well as other gas distributor implementations. The precursor and dilution gas distribution profile adjacent to the substrate may match (or substantially match) a desired thickness profile of material deposited on a substrate. The desired thickness profile may be described by a polynomial function, such as a second or higher order polynomial function. Various features and/or designs of showerhead pedestals for providing such tailored thickness profiles will be described in association with FIGS. 7–26. In some implementations, precursor and dilution gas output may be divided into multiple zones in order to produce a particular thickness profile, as will become more apparent below. It is also contemplated that precursor and dilution gas output may be interlaced, alternated, or otherwise integrated within one or more other zones to further control, e.g., smoothen a desired profile within and/or between one or more zones, etc.) to further produce a particular thickness profile, as will become more apparent below.

[0114] FIG. 6A is a graph comparing a desired profile and simulated profiles for reactant gas flowing from variously configured gas distributors relative to a backside of a substrate according to some embodiments. FIG. 6B is a graph comparing a desired profile and simulated profiles for dilution gas flowing from variously configured gas distributors relative to a backside of a substrate according to some embodiments.

[0115] Referring to FIGS. 6A and 6B, reactant and dilution gas concentration from a showerhead pedestal is shown relative to locations on a gas output surface of the showerhead pedestal. The locations extend along a radial direction, which may extend in the x-axis or y-axis direction. Gas concentration of desired profiles **601** and **603** for a first gas (e.g., a reactant gas) and a second gas (e.g., a dilution gas) generally follow respective parabolic curves. Desired profile **601** exhibits maximum concentration at a center of the showerhead pedestal

and zero (or substantially zero) concentration an edge of the showerhead pedestal. Desired profile **603** exhibits maximum concentration at the edge of the showerhead pedestal and zero (or substantially zero) concentration at the center of the showerhead pedestal. Simulated profiles **605** and **607** may not perfectly match desired profiles **601** and **603**, but may substantially match desired profiles **601** and **603** to achieve a sufficient deposition profile on a backside of a substrate. An observed or simulated curve may be considered to “substantially match” a parabolic or polynomial curve based upon fitting the observed curve to a polynomial function and evaluating the residuals therebetween to determine an acceptable level of correlation. For instance, when a statistical measure (such as R-square or an adjusted R-square) of the residuals reaches or exceeds a predetermined confidence level, the observed curve may be considered to “substantially match” the polynomial function. According to various embodiments, a gas distributor may be configured to output a gas concentration profile that substantially matches a desired parabolic or polynomial function. Simulated profiles **605** and **607** will be described in more detail after various gas distribution features of some example showerhead pedestals are explored.

[0116] According to various embodiments, a gas distributor is used to distribute one or more gases, such as one or more process (or reactant) gases and/or one or more dilution gases, in an area adjacent to (e.g., over or under) a substrate in a process chamber. Generally, the gas distributor has a first surface and a second surface, each of which includes ports (or holes) that are fluidically interposed between an interior and an exterior of a main body of the gas distributor. The first surface defines a portion of the main body that, during a semiconductor process, faces towards a location in the process chamber where a wafer may be positioned during processing operations. The first surface may include a plurality of gas distribution ports, which are openings or apertures that permit gas to be delivered from within the gas distributor towards the substrate. The second surface defines a portion of the main body that faces away from the location in the process chamber where a wafer may be positioned during processing operations. In a plan view, each of the first and second surfaces may have a circular (or substantially circular) shape, but embodiments are not limited thereto. In other words, any other geometric or freeform configuration may be utilized. At least one third surface may extend between the first and second surfaces to enclose one or more volumes (e.g., plenum volumes) within the gas distributor. These one or more volumes may define portions of one or more gas distribution flow paths interior to the gas distributor and may be defined by one or more through-holes (or passages), cavities, recessed portions, risers, and/or elongated holes in an interior of the gas distributor. One or more gas inlets may interface with the second surface

to deliver one or more gases for distribution. In some embodiments, the one or more gas inlets are provided in a coaxial, multi-feed gas delivery stem connected to the second surface. Gas within the one or more volumes exits the gas distributor by flowing out of the plurality of gas distribution ports. Some example architectures of a gas distributor are described in association with FIGS. 7–26 in the context of various showerhead pedestal implementations. As previously mentioned, a showerhead pedestal is a showerhead configured to deliver gas(es) to a backside of a substrate.

[0117] FIG. 7 schematically illustrates a perspective view of a gas distributor (e.g., a showerhead pedestal) according to some embodiments. FIG. 8 schematically illustrates an orthographic view of a portion of a surface (e.g., a lower surface) of the gas distributor of FIG. 7 according to some embodiments.

[0118] Referring to FIGS. 7 and 8, showerhead pedestal **700** includes main body **701** and stem **703**. Main body **701** has first surface **705** and second surface **707** opposing first surface **705** in a first direction, such as a direction extending parallel to the z-axis direction. Longitudinal axis **708** of showerhead pedestal **700** may also extend parallel or substantially parallel to the z-axis direction. Accordingly, a thickness of main body **701** is defined along longitudinal axis **708** in the first direction. First surface **705** includes a plurality of gas distribution ports (e.g., gas distribution ports **709**), which may be arranged in a gas distribution area (or area) **711** and may be divided into a plurality of zones (or groups), such as zones **713**. Zones **713** may longitudinally extend in a second direction transverse to the first direction (e.g., the second direction may extend parallel to the y-axis direction), and may be adjacent to one another along a third direction transverse to both the first direction and the second direction (e.g., the third direction may extend parallel or substantially parallel to the x-axis direction). Although four zones are shown, embodiments are not limited thereto. For example, the gas distribution ports of area **711** may be divided into three or less zones or divided into five or more zones. It is also contemplated that the gas distribution ports of at least one zone may be divided into one or one sub-zones and/or sub-portions.

[0119] According to various embodiments, the gas distribution ports of area **711** may distribute one or more gases, such as one or more process (or reactant) gases and/or one or more dilution gases, in an area adjacent to a backside of a substrate in a process chamber. For instance, one or more first gases may be flowed from the gas distribution ports of a first zone among zones **713**, and one or more first gases and one or more second gases may be flowed from the gas distribution ports of at least one second zone among zones **713**. In some cases, the output of the one or more first gases from a second zone may be interlaced, alternated, or otherwise

integrated with the output of the one or more second gases flowed from the gas distribution ports of that second zone. For instance, gas distribution ports of a second zone that are adjacent to one another in at least one of the second direction and the third direction may be fluidically connected to different supply plenums formed within main body **701**, and thereby, configured to output different gases from one another. Embodiments, however, are not limited to the aforementioned examples. For instance, the gas distribution ports of a zone, sub-zone, or sub-portion may be interlaced, alternated, or otherwise integrated in any suitable manner to achieve a desired gas distribution profile, such as interlaced, alternated, or otherwise integrated in groups of gas distribution ports of the one or more first gases and the one or more second gases along, for instance, at least one of the second and third directions with each group including one or more gas distribution ports. In some cases, the groups may have at least one of a linear, geometric, variable, etc., arrangement of gas distribution ports. Whatever the case, the interlaced, alternated, or otherwise integrated arrangement of gas distribution ports configured to output one or more first gases and one or more second gases in various zones, sub-zones, and/or sub-portions may enable precise control over the gas distribution profile across first surface **705** of main body **701**.

[0120] In some implementations, second surface **707** of showerhead pedestal **700** may include first inlet **715** and second inlet **717**. Second inlet **717** may encircle first inlet **715**, and in some embodiments, first inlet **715** may be concentrically aligned with second inlet **717**. First inlet **715** may be fluidically connected with a first supply plenum among the supply plenums formed within main body **701**. Second inlet **717** may be fluidically connected with a second supply plenum among the supply plenums formed within main body **701** that is distinct from the first supply plenum.

[0121] According to various embodiments, one or more gases are supplied to showerhead pedestal **700** in distinct or partially mixed states. As such, showerhead pedestal **700** may include one or more tortuous flow paths configured to induce turbulent flow as one or more received gases flow therethrough and prior to being received within an interior of main body **701**. In some implementations, the tortuous flow paths are made part of stem **703**. Such a configuration can supplant (or be utilized in association with) conventional, external mixing assemblies, and as such, can reduce tool costs and/or increase mixing effects. Some example configurations of stem **703** are described in association with FIGS. 9–26.

[0122] FIGS. 9 and 10 schematically illustrate perspective views of a stem body of the gas distributor of FIG. 7 according to some embodiments. FIG. 11 schematically illustrates an exploded perspective view of the stem body of FIG. 9 according to some embodiments. FIG.

12 schematically illustrates a cross-sectional view of the stem body according to some embodiments. FIGS. 13–16 schematically illustrate cross-sectional views of the stem body of FIG. 12 respectively taken along sectional lines **13–13**, **14–14**, **15–15**, and **16–16** according to some embodiments. FIGS. 17–19 schematically illustrate various flow paths within the stem body of FIG. 9 according to some embodiments. FIG. 20 schematically illustrates a perspective view of an extension of the stem body of FIG. 9 according to some embodiments. FIG. 21 schematically illustrates a cross-sectional view of the extension of FIG. 20 taken along sectional line **21–21** according to some embodiments. FIG. 22 schematically illustrates a perspective view of a sleeve of the stem body of FIG. 9 according to some embodiments. FIG. 23 schematically illustrates a cross-sectional view of the sleeve of FIG. 22 taken along sectional line **23–23** according to some embodiments. FIG. 24 schematically illustrates a perspective view of a core of the stem body of FIG. 9 according to some embodiments. FIG. 25 schematically illustrates a cross-sectional view of the core of FIG. 24 taken along sectional line **25–25** according to some embodiments. FIG. 26 schematically illustrates an orthographic view of a proximal end of the core of FIG. 24 according to some embodiments.

[0123] Referring to FIGS. 9–26, stem **703** may include sleeve **901**, core **903**, and extension **905** that, in some implementations, may be separate structures that are joined or otherwise assembled together to form a stem body. It is contemplated, however, that sleeve **901**, core **903**, and extension **905** may be formed as portions of a single, contiguous body, which may be formed via one or more additive manufacturing process. In other instances, two components among sleeve **901**, core **903**, and extension **905** may be formed as portions of a same body and the remaining component may be joined or otherwise assembled therewith to form the stem body. For example, core **903** and extension **905** may be formed as a single, contiguous structure and sleeve **901** may be joined or otherwise assembled therewith to form the stem body. Whatever the case, distal end portion **907** of stem **703** may be connected to second surface **707** of main body **701**, such as by being welded or otherwise affixed to second surface **707** of main body **701**.

[0124] According to various embodiments, stem **703** may include a plurality of interior flow paths, such as first interior flow path **1701** and second interior flow path **1703**, with each interior flow path being configured to distinctly deliver one or more gases to main body **701**. It is noted that the depictions in FIGS. 17–19 are representative of the void (or negative) space formed within stem **703** that provides pathways for the traversal of the plurality of interior flow paths. In some cases, first interior flow path **1701** is configured to deliver the one or more first gases in a mixed or partially mixed state to a first inlet of main body **701**, and second interior

flow path **1703** is configured to deliver the one or more second gases in a mixed or partially mixed state to a second inlet of main body **701** that is distinct from the first inlet of main body **701**. As such, stem **703** includes proximal end portion **909** having a plurality of inlets (e.g., inlets **1001** and **1003**) and distal end portion **907** opposing proximal end portion **909** along longitudinal axis **1101** of stem **703** and including a plurality of outlets, such as first and second outlets **911** and **913**. As used herein, the terms “proximal” and “distal” refer, respectively, to directions closer to and farther away from a particular reference point, such as a source of gas flow. In this sense, an element referred to as being “proximal” may conversely be referred to as being “distal” depending on the particular reference point chosen without departing from the teachings of the disclosure.

[0125] It is also noted that distal end portion **907** may include one or more interfacing portions configured to engage with corresponding inlets to main body **701**. For example, distal end portion **907** may include first interfacing portion **1201** configured to engage with the first inlet of main body **701** and second interfacing portion **1203** configured to engage with the second inlet of main body **701**. At least one of first and second interfacing portions **1201** and **1203** may be flanged or otherwise structured to facilitate the coupling of stem **703** with main body **701**. As shown, first interfacing portion **1201** is flanged and second interfacing portion **1203** includes bore region **2301**, which has a different cross-sectional area in a plane perpendicular to longitudinal axis **2303** of sleeve **901** than main bore region **2305**. The cross-sectional area of bore region **2301** may, in some cases, be smaller than the cross-sectional area of main bore region **2305**, but embodiments are not limited thereto.

[0126] Before delving further into the respective configurations of first interior flow path **1701** and second interior flow path **1703**, the corresponding structures of sleeve **901**, core **903**, and extension **905** will be discussed in more detail to provide some context to the formation of the aforementioned void space within stem **703** and, thereby, the formation of first interior flow path **1701** and second interior flow path **1703**.

[0127] With particular reference to FIGS. 9–12, 20, and 21, extension **905** may include first part **2001**, second part **2003** arranged opposite first part **2001**, and third part **2005** extending between first part **2001** and second part **2003**. First part **2001** may define proximal end portion **909** of stem **703** and may be configured to interface with one or more supply conduits fluidically connected with one or more gas sources. In this manner, first part **2001** may include flanged region **2007** having one or more apertures (e.g., apertures **1005**) configured to allow proximal end portion **909** of stem **703** to be connected with the one or more aforementioned supply conduits using, for example, one or more fasteners, such as one or more screws, bolts,

nuts, rivets, and/or the like. In some cases, the one or more supply conduits may be housed within a common supply line, but embodiments are not limited thereto. In such implementations, flanged region **2007** may include mating surface **2009** configured to interface with (or abut against) a corresponding mating surface of the common supply line to enable inlets **1001** and **1003** to be fluidically connected with corresponding outlets of the one or more supply conduits. Mating surface **2009** may include recessed region **1007** configured to support at least one gasket (e.g., O-ring, seal, and/or the like) at least partially therein. To this end, recessed region **1007** may encircle inlets **1001** and **1003**, which may define respective openings into corresponding bores (e.g., bores **2101** and **2103**) that respectively extend into first part **2001** along longitudinal axis **2105** of extension **905**. In some cases, mating surface **2009** may include protrusion **2011** that includes inlet **1003** to allow inlet **1003** to be offset from inlet **1001**, which may be formed in mating surface **2009**. As such, inlet **1003** may be offset from inlet **1001** by distance **2107** along longitudinal axis **2105**. It is also contemplated that inlets **1001** and **1003** may be respectively offset from longitudinal axis **2105** by distances **2109** and **2111**, and as such, corresponding central axes **2113** and **2115** of inlets **1001** and **1003** (and bores **2101** and **2103**) may also be offset from longitudinal axis **2105** by distances **2109** and **2111**.

[0128] As previously mentioned, second part **2003** of extension **905** may be connected to first part **2001** via third part **2005**, which may extend from first part **2001** along longitudinal axis **2105**. Second and third parts **2003** and **2005** may include bores **2117** and **2119** having respective central axes **2121** and **2123** that also extend along longitudinal axis **2105**, but may be arranged respectively closer to longitudinal axis **2105** than central axes **2113** and **2115**. That being said, bores **2117** and **2119** may be fluidically connected with bores **2101** and **2103** to form corresponding first and second interior supply paths **1705** and **1707** in extension **905**. In some cases, bores **2117** and **2119** may be gun drilled from at least one distal surface of second part **2003** towards first part **2001** and bores **2101** and **2103** may be gun drilled from at least one proximal surface of first part **2001** towards second part **2003** in a manner that physically and fluidically connects bores **2117** and **2119** respectively with bores **2101** and **2103** within extension **905**.

[0129] Second part **2003** of extension **905** may include first body portion **2013** having a first cross-sectional area in plane **2013p**, second body portion **2015** having a second cross-sectional area in plane **2015p**, and third body portion **2017** having a third cross-sectional area in plane **2017p**. Each of planes **2013p**, **2015p**, and **2017p** may extend perpendicular to longitudinal axis **2105** of extension **905**. In some implementations, the first cross-sectional area of first body portion **2013** may be greater than the second cross-sectional area of second body portion

2015, and the second cross-sectional area of second body portion **2015** may be greater than the third cross-sectional area of third body portion **2017**, but embodiments are not limited thereto. To this end, first body portion **2013** may, in some cases, be connected with first part **2001**, and second body portion **2015** may protrude from a central region of distal surface **2125** of first body portion **2013**. Third body portion **2017** may, in some implementations, protrude from a central region of distal surface **2127** of second body portion **2015**. As such, respective portions of first interior flow path **1701** may extend through each of first body portion **2013**, second body portion **2015**, and third body portion **2017**, and respective portions of second interior flow path **1703** may extend through each of first body portion **2013** and second body portion **2015**. In this manner, distal surface **2129** of third body portion **2017** may include opening **2131** defining an outlet of first interior supply path **1705** from extension **905**, and distal surface **2127** of second body portion **2015** may include opening **2133** defining an outlet of second interior supply path **1707** from extension **905**. Similar to inlets **1001** and **1003**, openings **2131** and **2133** may be offset from one another along longitudinal axis **2105** by distance **2135** such that opening **2131** is arranged further from mating surface **2009** than opening **2133**.

[0130] Adverting to FIGS. 9, 11, 22, and 23, sleeve **901** may have proximal end **2201** and distal end **2203** arranged at opposing ends of sleeve **901**. In some cases, sleeve **901** may have an interior region that is accessible via first opening **2307** located at proximal end **2201** of sleeve **901** and second opening **2309** located at distal end **2203** of sleeve **901**. As such, sleeve **901** may, as shown, be generally tubular in shape having one or more internal surfaces (e.g., internal surface **2311**), but may also include portions or sections with different internal or external dimensions or areas. For instance, a region of sleeve **901** formed in association with plane **2313** (and, thereby, in association with second interfacing portion **1203** of stem **703**) may have a smaller internal cross-sectional area than a region of sleeve **901** formed in association with, for example, plane **2315**. Each of planes **2313** and **2315** may extend perpendicular to longitudinal axis **2303** of sleeve **901**. When assembled as part of stem **703**, sleeve **901** may be joined with extension **905** such that proximal end **2201** of sleeve **901** is made to abut against distal surface **2125** of extension **905**, and second and third body portions **2015** and **2017** of extension **905** are received in first opening **2307** in sleeve **901**. In some cases, corresponding faces and/or perimeters of proximal end **2201** of sleeve **901** and distal surface **2125** of extension **905** may be joined together via, for instance, any suitable technique, such as brazing, friction-stir welding, soldering, and/or the like. To this end, internal surface **2311** of sleeve **901** may, in some cases, abut against a corresponding external surface of second body portion **2015** of extension **905**, whereas an external surface of third body portion **2017** of extension **905** may

be spaced apart from internal surface **2311**, but embodiments are not limited thereto. It is noted, however, that core **903** may be joined with extension **905** prior to sleeve **901** being joined with extension **905**.

[0131] Referring to FIGS. 11–13 and 24–26, core **903** may be a generally cylindrical body extending along longitudinal axis **2401** and having first end portion **2501** connected to second end portion **2503** via intermediate portion **2505**. First end portion **2501** of core **903** may terminate at proximal end **2507** having first opening **EB09** and second end portion **2503** of core **903** may terminate at distal end **2511** having second opening **2513**. In this manner, core **903** may have one or more exterior lateral surfaces, which are collectively represented in FIG. 25 via dashed line **903s** that at least partially bounds the body defining core **903**. Hereinafter, the exterior lateral surface(s) of core **903** will be referred to, either individually or collectively, as exterior **903s**. At least one internal passageway (e.g., internal passageway **2515**) may be formed through the body of core **903**, and thereby, fluidically connect first opening **2509** with second opening **2513** in an interior of core **903**. In some cases, internal passageway **2515** may be formed by the joining of bore **2517** extending from first opening **2509** in proximal end **2507** of core **903** along central axis **2521** and bore **2519** extending from second opening **2513** in distal end **2511** of core **903** along central axis **2523**. Central axis **2521** may be offset from longitudinal axis **2401** of core **903** in a direction transverse to a direction of extension of longitudinal axis **2401**. In some cases, central axis **2523** may be coincident with longitudinal axis **2401** of core **903**. It is also noted that bore **2517** may include one or more sections of different cross-sectional areas in corresponding planes perpendicular to central axis **2521**. For example, section **2517_1** of bore **2517** may have a greater cross-sectional area than section **2517_2** of bore **2517**. As will become more apparent below, section **2517_1** of bore **2517** may be sized relative to third body portion **2017** of extension **905** so that section **2517_1** can accommodate at least some of third body portion **2017** therein when core **903** and extension **905** are incorporated as part of stem **703**. Similar to the physical and fluidic connection of bores **2117** and **2119** respectively with bores **2101** and **2103** of extension **905**, bore **2517** may be gun-drilled from proximal end **2507** of core **903** towards distal end **2511** of core **903** to a first depth, and bore **2519** may be gun-drilled from distal end **2511** towards proximal end **2507** to a second depth such that bores **2517** and **2519** at least partially coincide and, thereby, become physically and fluidically connected within a central region of core **903**. In some cases, bores **2517** and **2519** may be physically and fluidically connected in a region of first end portion **2501**.

[0132] According to some embodiments, first end portion **2501** of core **903** may include a

plurality of first recesses (e.g., first recesses **2403**) in exterior **903s** that form corresponding first channels extending along respective longitudinal axes, such as longitudinal axis **2601**. The respective longitudinal axes of the first channels may extend parallel (or substantially parallel) to longitudinal axis **2401** of core **903**. For descriptive convenience, the plurality of first recesses will, hereinafter, be referred to collectively or individually as first recesses **2403** or first channels **2403**. In some cases, first recesses **2403** may have generally semicircular cross-sections in corresponding planes extending perpendicular to longitudinal axis **2401** of core **903**, but any other suitable cross-sectional area may be utilized. At least a first some of first recesses **2403** (such as first recesses **2403a**) may be circumferentially spaced apart from one another about longitudinal axis **2401** of core **903** by first angular distance (or angle) **2603**, and at least a second some of first recesses **2403** (such as first recesses **2403b**) may be circumferentially spaced apart from one another about longitudinal axis **2401** by second angular distance **2605**. In some cases, second angular distance **2605** may be greater than first angular distance **2603**. As such, adjacent first recesses among the first some of first recesses **2403** may be separated from one another by first septal walls (e.g., first septal walls **2607**), and adjacent first recesses among the second some of first recesses **2403** may be separated from one another by second septal walls (e.g., second septal wall **2609**). It is also noted that the second some of the first recesses **2403** may be arranged closer to bore **2517** than the first some of the first recesses **2403**, such as shown in FIG. 26. Accordingly, second angular distance **2605** may be sized to allow bore **2517** to be formed in a central region of first end portion **2501** of core **903** that is offset from longitudinal axis **2401** without interfering with any of first recesses **2403**.

[0133] Intermediate portion **2505** may, in some implementations, include a plurality of first sections (e.g., first sections **2405**) of reduced cross-sectional area in corresponding planes extending perpendicular to longitudinal axis **2401** relative to respective cross-sectional areas of a plurality of second sections (e.g., second sections **2407**) of intermediate portion **2505**. To this end, each of first sections **2405** and second sections **2407** may be axially spaced apart from one another along longitudinal axis **2401**, and in some cases, first sections **2405** and second sections **2407** may be alternately arranged along longitudinal axis **2401**. Each of first sections **2405** and second sections **2407** may include a respective portion of bore **2519** formed therein that, in turn, defines a corresponding portion of internal passageway **2515**.

[0134] With particular reference to FIGS. 15–13, 24, and 25, each of second sections **2407** may include a plurality of corresponding second recesses (e.g., second recesses **2409**) in exterior **903s** that form corresponding second channels extending along respective central axes, e.g., central axes **1301**, **1401**, and **1501**. The respective central axes of the second channels

may extend parallel (or substantially parallel) to longitudinal axis **2401** of core **903**. For descriptive convenience, the plurality of second recesses will, hereinafter, be referred to collectively or individually as second recesses **2409** or second channels **2409**.

[0135] Each of second recesses **2409** may have a generally semicircular cross-section in a corresponding plane extending perpendicular to longitudinal axis **2401** of core **903**, but any other suitable cross-sectional configuration may be utilized. In some embodiments, second recesses **2409** may be circumferentially spaced apart from one another about longitudinal axis **2401** of core **903** by third angular distance (or angle) **1303** and, thereby, separated from one another by corresponding septal walls **2411**. In some cases, third angular distance **1303** may be greater than first angular distance **2603** and less than second angular distance **2605**, but embodiments are not limited thereto. It is also contemplated that the spacing between adjacent second recesses **2409** of at least one of second sections **2407** may be different from the spacing between adjacent second recesses **2409** of at least another one of second sections **2407**. Moreover, although each of second sections **2407** is shown including four second recesses **2409** and a corresponding number of septal walls **2411**, embodiments are not limited thereto. For instance, at least one of second sections **2407** may have more or less second recesses than four and/or at least one of second sections **2407** may have a different amount of second recesses than at least another one of second sections **2407**. In some cases, each of second sections **2407** may include less second recesses **2409** than first end portion **2501** includes first recesses **2403**. As depicted, first end portion **2501** includes seven first recesses **2403**, but implementations are not limited thereto.

[0136] According to some embodiments, the central axes of the corresponding second recesses of one second section among second sections **2407** may be circumferentially offset from the central axes of the corresponding second recesses of another second section among second sections **2407**. For example, the central axes (e.g., central axis **1301**) of the corresponding second recesses (e.g., second recesses **1305**) of one second section (e.g., second section **2407_1**) among second sections **2407** may be circumferentially offset from the central axes (e.g., central axis **1401**) of the corresponding second recesses (e.g., second recesses **1405**) of another second section (e.g., second section **2407_2**) among second sections **2407** by fourth angular distance (or angle) **1403**. In this manner, central axes **1301** and **1401** may be incongruent. Similar to central axes **1301** and **1401**, central axes **1401** of the corresponding second recesses **1405** of second section **2407_2** may be circumferentially offset from the central axes (e.g., central axis **1501**) of the corresponding second recesses (e.g., second recesses **1505**) of yet another second section (e.g., second section **2407_3**) among second sections **2407**.

by fourth angular distance **1403** or another amount. As such, central axes **1401** and **1501** may be incongruent. In some cases, central axes **1301** of the corresponding second recesses **1305** of second section **2407_1** may be coincident with central axes **1501** of the corresponding second recesses **1505** of second section **2407_3**, but embodiments are not limited thereto. It is also contemplated that one or more of second sections **2407** may have a same corresponding axial length along longitudinal axis **2401** of core **903**, but implementations are not limited thereto. For instance, second section **2407_3** may have a different (e.g., greater) axial length than at least another one of second sections **2407**.

[0137] Second end portion **2503** of core **903** may, in some embodiments, include flanged portion **2413**, which may correspond to first interfacing portion **1201** of stem **703**. It is also noted that second end portion **2503** includes second opening **2513**, which may define first outlet **911** of first interior flow path **1701** of stem **703**. In some cases, second end portion **2503** may also include a portion of a first section among first sections **2405**, and thereby, include a region of reduced cross-sectional area in, for instance, plane **2503p** that extends perpendicular to longitudinal axis **2401** of core **903**. As will become more apparent below, an exterior of this region of second end portion **2503** and a corresponding portion of the interior of the sleeve **901** may define, at least in part, second outlet **913** of second interior flow path **1703** of stem **703**.

[0138] When assembled as part of stem **703**, proximal end **2507** of core **903** may be mated in relation to second part **2003** of extension **905** such that proximal end **2507** of core **903** is arranged closer to proximal end portion **909** of stem **703** than distal end **2511** of core **903**. In some implementations, third body portion **2017** of extension **905** may be at least partially received in section **2517_1** of bore **2517** of core **903** to physically and fluidically connect bore **2517** of core **903** with bore **2117** of extension **905**. In some cases, a perimeter (and, in some embodiments, at least one adjacent surface to the perimeter) of first opening **2509** to bore **2517** of core **903** may be joined together with a section of third body portion **2017** of extension **905** extending from bore **2517** via, for instance, any suitable technique, such as brazing, friction-stir welding, soldering, and/or the like. To this end, internal surface **2525** of bore **2517** may, in some cases, abut against a corresponding external surface of third body portion **2017** of extension **905**. The abutting surfaces and/or joining of core **903** with extension **905** may fluidically seal a flow path between bore **2517** of core **903** and bore **2117** of extension **905** to, thereby, form section **1709** of first interior flow path **1701** of stem **703**.

[0139] It is also contemplated that, when core **903** is assembled with extension **905**, proximal end **2507** of core **903** may be axially offset from distal surface **2127** of second body portion **2015** of extension **905**. Further, when sleeve **901** is joined with extension **905** having core **903**

joined therewith, at least a portion of core **903** may be supported within an interior region of sleeve **901** and, in some cases, second end portion **2503** of core **903** may extend out of second opening **2309** of sleeve **901**. With such a configuration, proximal end **2507** of core **903** may be arranged in the interior of sleeve **901** such that proximal end **2507** is axially offset from first opening **2307** in sleeve **901**. Further, one or more sections of internal surface **2311** of sleeve **901** may, in some cases, contact one or more corresponding portions of exterior **903s** of core **903**. The abutting surfaces and/or joining of sleeve **901** with extension **905** may, together with the interior of sleeve **901** and exterior of third body portion **2017** of extension **905**, at least partially bound plenum volume **1205** between opening **2133** of extension **905** (that defines the outlet of second interior supply path **1707**) and corresponding inlets (e.g., inlets **2415**) of first recesses **2403**. In this manner, plenum volume **1205** may fluidically connect inlets **2415** of first recesses **2403** of core **903** with second interior supply path **1707** in extension **905** to, thereby, form section **1711** of second interior flow path **1703** of stem **703**. It is also noted that corresponding longitudinal passageways **1713** may be formed, at least in part, by respective first recesses **2403** of core **903** and corresponding portions of internal surface **2311** of sleeve **901**. Each of longitudinal passageways **1713** may form respective portions of second interior flow path **1703** of stem **703** that are fluidically connected with section **1711** of second interior flow path **1703**. In this manner, one or more gases supplied to section **1711** of second interior flow path **1703** via second interior supply path **1707** in extension **905** may be distributed by section **1711** amongst longitudinal passageways **1713** of second interior flow path **1703** and, thereby, about longitudinal axis **1101** of stem **703** such that section **1711** of second interior flow path **1703** and the conjunction of longitudinal passageways **1713** encircles first interior flow path **1701**.

[0140] According to various embodiments, corresponding longitudinal passageways **1715** of second interior flow path **1703** may be formed, at least in part, by respective second recesses **2409** of core **903** and corresponding portions of internal surface **2311** of sleeve **901**. In addition, corresponding annular plenum volumes **1717** may be formed, at least in part, by respective exteriors of first sections **2405** of core **903** and corresponding portions of internal surface **2311** of sleeve **901**. Yet another annular plenum volume **1719** may be formed, at least in part, by a section of an exterior of second end portion **2503** of core **903** and a corresponding portion of internal surface **2311** of sleeve **901**. In some embodiments, first annular plenum volume **1717_1** among annular plenum volumes **1717** may fluidically connect longitudinal passageways **1713** of second interior flow path **1703** with first longitudinal passageways **1715_1** among longitudinal passageways **1715** of second interior flow path **1703**. Similarly,

second annular plenum volume **1717_2** among annular plenum volumes **1717** may fluidically connect first longitudinal passageways **1715_1** with second longitudinal passageways **1715_2** among longitudinal passageways **1715** of second interior flow path **1703**, and third annular plenum volume **1717_3** among annular plenum volumes **1717** may fluidically connect second longitudinal passageways **1715_2** with third longitudinal passageways **1715_3** among longitudinal passageways **1715** of second interior flow path **1703**. In some cases, the circumferential offset amongst first, second, and third longitudinal passageways **1715_1**, **1715_2**, and **1715_3** may create tortuosity in association with second interior flow path **1703** that may induce turbulent flow along longitudinal axis **1101** of stem **703** in response to a flow of one or more gases along second interior flow path **1703**. To this end, some amount of eddying and/or vortex formation may occur in association with at least one of plenum volumes **1717** as the one or more gases flow into and/or out of first, second, and third longitudinal passageways **1715_1**, **1715_2**, and **1715_3**. Annular plenum volume **1719** may fluidically connect third longitudinal passageways **1715_3** with second outlet **913** of stem **703**, and thereby, define an outlet of second interior flow path **1703**.

[0141] With reference to at least FIGS. 12, 16, and 17–19, bore **2519** of core **903** may form section **1721** of first interior flow path **1701** having first outlet **911** and being fluidically connected with section **1709** of first interior flow path **1701**. It is noted that the various portions of second interior flow path **1703** defined by longitudinal passageways **1713** and **1715** and annular plenum volumes **1717** and **1719** may encircle section **1721** of first interior flow path **1701** along longitudinal axis **1101** of stem **703**, and in some cases, may be concentrically aligned with section **1721** of first interior flow path **1701**. In this manner, second outlet **913** of second interior flow path **1703** may, when viewed along longitudinal axis **1101**, encircle first outlet **911** of first interior flow path **1701**, and in some embodiments, may be concentrically aligned with first outlet **911** first interior flow path **1701**.

[0142] According to some embodiments, a tortuosity of second interior flow path **1703** may be greater than a tortuosity of first interior flow path **1701**. As previously mentioned, stem **703** may be manufactured as a monolithic structure. For instance, one or more additive manufacturing techniques, such as direct laser metal sintering (or, if a ceramic stem is desired, a ceramic sintering process), may be utilized to form stem **703**. In this manner, each of the plurality of interior flow paths may define a corresponding contiguous void in stem **703**. As such, each of the plurality of interior flow paths may be fluidically isolated from one another within stem **703**. For instance, first interior flow path **1701** may be fluidically isolated from second interior flow path **1703** within stem **703** such that first interior flow path **1701** is

configured to supply the one or more first gases to first inlet **715** of main body **701** and second interior flow path **1703** is configured to supply the one or more first gases and one or more second gases to second inlet **717** of main body **701**. In other implementations, stem **703** may be manufactured from a plurality of components, such as sleeve **901**, core **903**, and extension **905**. Each of these components may be manufactured as separate structures using any suitable manufacturing technique(s), e.g., casting, machining, molding, etc.

[0143] Although stem **703** is shown including two interior flow paths, embodiments are not limited thereto. For instance, stem **703** may include three or more interior flow paths. As another example, stem **703** may include multiple stem bodies such that stem **703** includes greater than two interior flow paths.

[0144] FIG. 27 schematically illustrates substrate processing system (or system) **2700**, which may be used to process wafer **2701** according to some embodiments.

[0145] System **2700** includes chamber **2703**. A center column is configured to support a pedestal when a surface of wafer **2701** is being processed, e.g., a film is being formed on the surface of wafer **2701**. The pedestal, in accordance with some embodiments, may be referred to as showerhead pedestal **2705**. Showerhead **2707** is disposed over showerhead pedestal **2705**. In an embodiment, showerhead **2707** is electrically coupled to power supply **2709** via match network **2711**. As such, power supply **2709** may be controlled by control module **2713**, e.g., a controller. In some embodiments, power may be provided to showerhead pedestal **2705** instead of (or in addition to) showerhead **2707**. Control module **2713** is configured to operate system **2700** by executing one or more sequences of one or more instructions defining at least one process recipe. Depending on whether a frontside or backside of wafer **2701** is to receive a deposited film, control module **2713** may set various operational inputs for defining a process recipe, such as power levels, timing parameters, process gases, mechanical movement of wafer **2701**, height of wafer **2701** from showerhead pedestal **2705**, etc.

[0146] The center column may also include lift pins, which may be controlled by a lift pin control signal from, for instance, control module **2713**. The lift pins may be used to raise wafer **2701** from showerhead pedestal **2705** to allow an end-effector to pick wafer **2701** and to lower wafer **2701** after being placed by the end-effector. The end effector may also place wafer **2701** over spacers **2715**. As will be described below, spacers **2715** are sized to provide a controlled separation of wafer **2701** between a surface of showerhead **2707** facing wafer **2701** and a surface of showerhead pedestal **2705** facing wafer **2701**.

[0147] System **2700** further includes gas sources **2717** and **2719**, e.g., gas chemistry supplies from a facility and/or dilution (e.g., inert) gases. Depending on the processing being performed

relative to a surface of wafer **2701**, control module **2713** may control the delivery of gas sources **2717** to showerhead **2707** and/or showerhead pedestal **2705**. In some embodiments, gas manifold **2721** may be fluidically interposed between gas sources **2717** and showerhead **2707** and gas manifold **2723** may be fluidically interposed between gas sources **2719** and showerhead pedestal **2705**. Appropriate valving and mass flow control mechanisms may be employed and controlled via control module **2713** to ensure suitable gases are delivered during deposition and plasma treatment phases of a process. In some implementations, at least one of stem **2725** of showerhead **2707** and stem **2727** of showerhead pedestal **2705** may include one or more interior flow paths including one or more structures configured to induce turbulent flow along its longitudinal axis as received gas(es) are flowed to a corresponding main body of showerhead **2707** and showerhead pedestal **2705** from a respective one of gas sources **2717** and **2719**. In some embodiments, chamber **2703** may include openings **2703a** and **2703b** through which portions of stems **2725** and **2727** respectively extend. Example stem structures were described in association with at least FIGS. 9–26. Gas flow into showerhead **2707** and showerhead pedestal **2705** may be output, and, thereby, distributed in a space volume between wafer **2701** and a corresponding surface of showerhead **2707** and showerhead pedestal **2705** facing wafer **2701** via one or more gas distribution structures of showerhead **2707** and showerhead pedestal **2705**. Example gas distribution structures were at least described in association with FIGS. 7 and 8.

[0148] During substrate processing, spacers **2715** are configured to maintain a predetermined separation of wafer **2701** from a gas distribution surface of showerhead pedestal **2705** to facilitate (e.g., optimize) deposition to the backside of wafer **2701**, while reducing (or even preventing) deposition on the frontside of wafer **2701**. In some embodiments, while deposition is targeted for the backside of wafer **2701**, one or more inert gases may be flowed over the frontside of wafer **2701** via showerhead **2707** to push reactant gas away from the frontside of wafer **2701** and enable reactant gas(es) output from showerhead pedestal **2705** to be directed to the backside of wafer **2701**.

[0149] In various embodiments, process and/or dilution gases exit chamber **2703** via an outlet fluidically coupled to, for instance, vacuum pump **2729**, which may be a one or two stage mechanical dry pump and/or a turbomolecular pump. In this manner, process and/or dilution gases may be drawn out of chamber **2703** to maintain a suitably low pressure therein. To this end, a closed-loop flow restriction device, such as a throttle valve or a pendulum valve, may be controlled via control module **2713** to further ensure a suitably low pressure in chamber **2703**.

[0150] System 2700 may further include carrier ring 2731 encircling an outer region of showerhead pedestal 2705. When the frontside of wafer 2701 is being processed, e.g., a material is being deposited thereon, carrier ring 2731 is configured to sit over a carrier ring support region stepped down from a wafer support region in a center (or central portion) of showerhead pedestal 2705. Carrier ring 2731 includes an outer edge side of its disk structure, e.g., outer radius, and a wafer edge side of its disk structure, e.g., inner radius, that is closest to where wafer 2701 is supported. The wafer edge side of carrier ring 2731 may include a plurality of contact support structures configured to lift wafer 2701 when carrier ring 2731 is held by spacers 2715. In this manner, spider forks 2801 (see FIG. 28) may be used to lift and maintain carrier ring 2731 at a predetermined height during, for example, backside deposition processing, as well as utilized to rotate wafer 2701 about an axis perpendicular to a surface of, for instance, showerhead 2707 or showerhead pedestal 2705. Thus, carrier ring 2731 may also be lifted (or otherwise manipulated) along with wafer 2701 to be, for example, rotated to another station, e.g., in a multi-station system, such as multi-station processing tool 2800.

[0151] According to various embodiments, system 2700 may include or communicate with thermal management system 2733 to actively control the temperature of showerhead 2707 and/or showerhead pedestal 2705.

[0152] FIG. 28 schematically illustrates a multi-station processing tool configured for backside wafer deposition according to some embodiments.

[0153] In some implementations, multi-station processing tool 2800 can include an inbound load lock 2803 and an outbound load lock 2805, either or both of which may include a plasma source and/or an ultraviolet (UV) source. Robot 2807, at atmospheric pressure, is configured to move wafers from a cassette loaded through pod 2809 into inbound load lock 2803 via an atmospheric port 2811. Wafer 2701 is placed by robot 2807 on pedestal 2813 in inbound load lock 2803, atmospheric port 2811 is closed, and inbound load lock 2803 is pumped down. In instances in which inbound load lock 2803 includes a remote plasma source, wafer 2701 may be exposed to a remote plasma treatment in inbound load lock 2803 prior to being introduced into processing chamber 2815. Further, wafer 2701 may be heated in inbound load lock 2803 to, for example, remove moisture and/or adsorbed gases. Next, chamber transport port 2817 to processing chamber 2815 is opened, and another robot 2819 places wafer 2701 into the reactor on a pedestal of a first station shown in the reactor for processing. While the implementation depicted in FIG. 28 includes load locks, it will be appreciated that, in some implementations, direct entry of wafer 2701 into a processing station may be provided.

[0154] As seen in FIG. 28, processing chamber 2815 includes four process stations, numbered

1 to 4. Each station has a temperature-controlled pedestal (such as temperature-controlled pedestal **2821** of station 1), and gas line inlets. It will be appreciated that, in some cases, each process station may have different or multiple purposes. For example, in some embodiments, a process station may be switchable between a CVD and PECVD process mode. In another example, deposition operations, such as PECVD operations, may be performed in one station, while exposure to UV radiation for UV curing may be performed in another station. In some embodiments, deposition and UV curing may be performed in the same station. Further, although processing chamber **2815** shown as including four stations, embodiments are not limited thereto. For example, processing chamber **2815** may have any suitable number of stations, such as five or more stations, or three or less stations.

[0155] As previously mentioned, multi-station processing tool **2800** may include a wafer handling system (e.g., robot **2819** including spider forks **2801**) for transferring and/or positioning wafers within processing chamber **2815**. In some embodiments, the wafer handling system may transfer wafers between various process stations and/or between a process station and a load lock. It is contemplated, however, that any suitable wafer handling system may be employed, such as, for example, wafer carousels, other wafer handling robots, etc. Further, multi-station processing tool **2800** may include (or otherwise be coupled to) a system controller **2823** employed to control process conditions and hardware states of multi-station processing tool **2800**. System controller **2823** may include one or more memory devices **2825**, one or more mass storage devices **2827**, and one or more processors **2829**. Each processor **2829** may include a central processing unit (CPU) or computer, analog, and/or digital input/output connections, stepper motor controller boards, etc.

[0156] In some embodiments, system controller **2823** controls each of the activities of multi-station processing tool **2800**. For instance, system controller **2823** may execute system control software **2831** stored in mass storage device **2827**, loaded into memory device **2825**, and executed by processor **2829**. Alternatively, control logic may be hard coded in system controller **2823**. Application specific integrated circuits (ASIC), programmable logic devices (e.g., field-programmable gate arrays (FPGAs)) and/or the like may be used for these purposes. In the following discussion, wherever “software” or “code” is used, functionally comparable hard coded logic may be used in its place. System control software **2831** may include instructions for controlling the timing, mixture of gases, gas flow rates, chamber and/or station pressure, chamber and/or station temperature, wafer temperature, target power levels, RF power levels, substrate pedestal, chuck and/or susceptor position, and other parameters of a particular process performed by multi-station processing tool **2800**. System control software

2831 may be configured in any suitable way. For example, various process tool component subroutines or control objects may be written to control operation of the process tool components used to carry out various process tool processes. System control software **2831** may be coded in any suitable computer readable programming language.

[0157] In some embodiments, system control software **2831** may include input/output control (IOC) sequencing instructions for controlling the various parameters described above. Other computer software and/or programs stored on mass storage device **2827** and/or memory device **2825** associated with system controller **2823** may be employed in some embodiments. Examples of programs or sections of programs for this purpose include a substrate positioning program, a process gas control program, a pressure control program, a heater control program, a cooler control program, and a plasma control program.

[0158] A substrate positioning program may include program code for process tool components that are used to load and orientate wafer **2701** on pedestal **2821** and to control the spacing between wafer **2701** and other parts of multi-station processing tool **2800**.

[0159] A process gas control program may include code for controlling gas composition (e.g., silicon-containing gases, oxygen-containing gases, nitrogen-containing gases, dilution (or inert) gases, etc., as described herein) and flow rates and optionally for flowing gas into one or more process stations prior to deposition to stabilize the pressure in the process station. A pressure control program may include code for controlling the pressure in the process station by regulating, for example, a throttle valve in an exhaust system of the process station, a gas flow into the process station, etc.

[0160] A heater control program may include code for controlling current to a heating unit used to heat a gas distributor (e.g., showerhead **2707**, showerhead pedestal **2705**, etc.), and, thereby, heat wafer **2701**. Alternatively, the heater control program may control delivery of a heat transfer gas (such as helium) to a gas distributor, and, thereby, wafer **2701**.

[0161] A cooler control program may include code for controlling a flow rate of fluid (e.g., clean dry air (CDA), coolant, etc.) through a cooling unit used to extract heat from a gas distributor, such as showerhead **2707**, showerhead pedestal **2705**, etc., and transfer such thermal energy to, for instance, a waste heat capturing, storage, recycling, and/or disposing system.

[0162] A plasma control program may include code for setting RF power levels applied to the process electrodes in one or more process stations in accordance with various embodiments.

[0163] A pressure control program may include code for maintaining pressure in a reaction chamber in accordance with various embodiments.

[0164] In some embodiments, a user interface may be provided in association with system controller **2823**. The user interface may include a display screen, graphical software displays of the apparatus and/or process conditions, and user input devices, such as pointing devices, keyboards, touch screens, microphones, etc.

[0165] In some embodiments, parameters adjusted by system controller **2823** may relate to process conditions. Non-limiting examples include process gas composition and flow rates, temperature, pressure, plasma conditions (such as RF bias power levels), pressure, temperature, etc. These parameters may be provided to the user in the form of a recipe, which may be entered utilizing the user interface.

[0166] Signals for monitoring the process may be provided by analog and/or digital input connections of system controller **2823** from various process tool sensors. The signals for controlling the process may be output on analog and/or digital output connections of multi-station process tool **2800**. Non-limiting examples of process tool sensors that may be monitored include mass flow controllers, pressure sensors (such as manometers), thermocouples, etc. Appropriately programmed feedback and control algorithms may be used with data from the sensors to maintain process conditions.

[0167] System controller **2823** may provide program instructions for implementing one or more of the above-described processes. The program instructions may control a variety of process parameters, such as DC power level, RF bias power level, pressure, temperature, etc. The instructions may control the parameters to operate deposition of film stacks of a stress compensation layer according to various embodiments.

[0168] The system controller **2823** will typically include one or more memory devices and one or more processors configured to execute the instructions so that the apparatus will perform a method in accordance with some embodiments. In some instances, machine-readable media containing instructions for controlling process operations in accordance with various embodiments may be coupled to system controller **2823**.

[0169] In some embodiments, system controller **2823** may be part of a system, which may be part of at least one of the above-described examples. Such systems may include semiconductor processing equipment, including a processing tool or tools, a chamber or chambers, a platform or platforms for processing, and/or specific processing components (e.g., a wafer pedestal, a gas flow system, a thermal management system, etc.). The systems discussed above may be integrated with electronics for controlling their operation before, during, and/or after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. For

instance, system controller **2823**, 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), valve operation, light source control for radiative heating, 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 operational settings, wafer transfers into and out of a tool or chamber and other transfer tools and/or load locks connected to or interfaced with a specific system. In this manner, system controller **2823** may be configured to control, among other systems, the various actuators and motors of a backside wafer processing system.

[0170] Broadly speaking, system controller **2823** may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and/or 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). Program instructions may be instructions communicated to system controller **2823** 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 embodiments, 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 oxide, surfaces, circuits, dies of a wafer, etc.

[0171] System controller **2823**, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the system, otherwise networked to the system, or a combination thereof. For example, system controller **2823** may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of 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. 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 is to 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. Thus, as described above, system controller **2823** may be distributed, such as by including 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.

[0172] 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/or any other semiconductor processing system that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0173] As noted above, depending on the process step or steps to be performed by the tool, system controller **2823** 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, and/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.

[0174] Example Embodiments:

[0175] Embodiment 1: An apparatus for semiconductor processing, the apparatus comprising a stem body. The stem body comprising: a proximal end portion comprising a plurality of inlets, each of the inlets being distinct from one another and configured to receive a corresponding one or more gases; and a distal end portion arranged opposite the proximal end portion along a longitudinal axis of the stem body, the distal end portion being configured to interface with a gas distributor of a semiconductor processing apparatus, the distal end portion comprising a plurality of outlets, at least one of the outlets being distinct from at least another one of the outlets. The apparatus also comprising a plurality of interior flow paths comprising a first

interior flow path and a second interior flow path, each of the interior flow paths extending between a corresponding inlet among the inlets and at least one corresponding outlet among the outlets such that the interior flow paths are distinct from one another, at least one of the interior flow paths comprising one or more structures configured to induce turbulent flow along the longitudinal axis of the stem body in response to a flow of the corresponding one or more gases therealong.

[0176] Embodiment 2: The apparatus of embodiment 1, wherein, in a section of the stem body, the second interior flow path encircles the first interior flow path along the longitudinal axis.

[0177] Embodiment 3: The apparatus of embodiment 2, wherein, in the section of the stem body, the first interior flow path is concentrically aligned with the second interior flow path.

[0178] Embodiment 4: The apparatus of any one of embodiments 1-3, wherein the one or more structures comprise one or more first structures and each of the first structures comprises a corresponding internal passageway extending along the longitudinal axis of the stem body and defining a respective first portion of the first interior flow path; and a corresponding plurality of first channels extending along the longitudinal axis of the stem body and defining respective first portions of the second interior flow path, the corresponding first channels being circumferentially spaced apart from one another about the longitudinal axis of the stem body.

[0179] Embodiment 5: The apparatus of embodiment 4, wherein each of the corresponding internal passageways is coaxially aligned with the longitudinal axis of the stem body and fluidically connected with one another.

[0180] Embodiment 6: The apparatus of embodiment 4 or embodiment 5, wherein the one or more structures comprises multiple first structures axially arranged along the longitudinal axis of the stem body; and first central axes of the corresponding first channels of one first structure among the multiple first structures are circumferentially offset from second central axes of the corresponding first channels of another first structure among the multiple first structures.

[0181] Embodiment 7: The apparatus of embodiment 6, wherein the first central axes are incongruent with the second central axes.

[0182] Embodiment 8: The apparatus of any one of embodiments 4-7, wherein the stem body comprises a sleeve and a core; the sleeve comprises an interior that contacts an exterior of the core; each of the corresponding internal passageways extends in a central portion of the core; and each of the corresponding first channels is formed as a respective first recess in the exterior of the core such that a corresponding first longitudinal passageway is formed, at least in part, by that respective first channel and a corresponding portion of the interior of the sleeve.

[0183] Embodiment 9: The apparatus of any one of embodiments 1-8, wherein the one or more

structures comprise a second structure; the second structure comprises: a first interior bore having a first longitudinal axis; a second interior bore having a second longitudinal axis offset from the first longitudinal axis, the second interior bore being fluidically connected with the first interior bore; and a plurality of second channels extending along the longitudinal axis of the stem body and defining respective second portions of the second interior flow path, the second channels being circumferentially spaced apart from one another about the longitudinal axis of the stem body.

[0184] Embodiment 10: The apparatus of embodiment 9, wherein when directly or indirectly dependent from claim 4, wherein the one or more structures comprise three first structures and one second structure.

[0185] Embodiment 11: The apparatus of embodiment 9, wherein when directly or indirectly dependent from claim 4, wherein the second structure comprises more second channels than the first structure comprises first channels.

[0186] Embodiment 12: The apparatus of any one of embodiments 9-11, wherein each of the first interior bore and the second interior bore extends in the central portion of the core; the second interior bore is fluidically connected with at least one of the corresponding internal passageways; and each of the second channels is formed as a respective second recess in the exterior of the core such that a corresponding second longitudinal passageway is formed, at least in part, by that respective second channel and a corresponding portion of the interior of the sleeve.

[0187] Embodiment 13: The apparatus of any one of embodiments 9-12, wherein at least two directly adjacent second channels among the second channels are circumferentially spaced apart by a different amount than at least another two directly adjacent second channels among the second channels.

[0188] Embodiment 14: The apparatus of embodiment 12 or embodiment 13, wherein the second longitudinal passageways are arranged closer to the proximal end portion than the first longitudinal passageways.

[0189] Embodiment 15: The apparatus of any one of embodiments 8-14, wherein the sleeve comprises a first opening and a second opening fluidically connected with the first opening, the first opening being closer to the proximal end portion than the second opening; the core comprises a first end portion and a second end portion, the first end portion being closer to the proximal end portion than the second end portion; the second end portion extends out of the second opening and comprises the at least one corresponding outlet of the first interior flow path, the second end portion having a section of reduced cross-sectional area in a plane

perpendicular to the longitudinal axis; and the at least one corresponding outlet of the second interior flow path is defined, at least in part, by an exterior of the section of reduced cross-sectional area of the second end portion and a corresponding portion of the interior of the sleeve.

[0190] Embodiment 16: The apparatus of embodiment 15, wherein the at least one corresponding outlet of the first interior flow path is concentrically aligned with the at least one corresponding outlet of the second interior flow path.

[0191] Embodiment 17: The apparatus of any one of embodiments 8-16, wherein the stem body further comprises an extension; a first part of the extension defines the proximal end portion; a second part of the extension interfaces with each of the sleeve and the core; and the extension comprises: a first interior supply path fluidically connected with at least one of the corresponding internal passageways and defining a portion of the first interior flow path; and a second interior supply path fluidically connected with at least one of the corresponding first channels and defining a portion of the second interior flow path.

[0192] Embodiment 18: The apparatus of embodiment 17, wherein the first end portion is arranged within the sleeve such that each of an inlet of the first interior bore and inlets of the second channels is axially offset from the first opening; the second part of the extension comprises: a first body portion having a first cross-sectional area in a plane perpendicular to the longitudinal axis, the first body portion comprising respective portions of each of the first interior supply path and the second interior supply path; a second body portion protruding from a central portion of the first body portion and having a second cross-sectional area in the plane perpendicular to the longitudinal axis, the second cross-sectional area being smaller than the first cross-sectional area, the second body portion comprising a respective portion of the first interior supply path and an outlet of the second interior supply path; and a third body portion protruding from a central portion of the second body portion and having a third cross-sectional area in the plane perpendicular to the longitudinal axis, the third cross-sectional area being smaller than the second cross-sectional area, the third body portion comprising a respective portion of the first interior supply path and an outlet of the first interior supply path; the third body portion extends into the first opening and interfaces with the first interior bore to fluidically connect the outlet of the first interior supply path with the inlet of the first interior bore; the second body portion extends into the first opening and, together with the interior of the sleeve and an exterior of the third body portion, at least partially bounds a plenum volume between the outlet of the second interior supply path and the inlets of the second channels; and the plenum volume fluidically connects the outlet of the second interior supply path with the

inlets of the second channels.

[0193] Embodiment 19: The apparatus of embodiment 17 or embodiment 18, wherein at least one of a central axis of the first interior supply path and a central axis of the second interior supply path is offset from the longitudinal axis of the stem body.

[0194] Embodiment 20: The apparatus of embodiment 19, wherein each of the central axis of the first interior supply path and the central axis of the second interior supply path is offset from the longitudinal axis of the stem body.

[0195] Embodiment 21: The apparatus of embodiment 18, wherein a proximal end of the core is welded to the third body portion; and a proximal end of the sleeve is welded to the first body portion.

[0196] Embodiment 22: The apparatus of any one of embodiments 1-21, wherein the interior flows paths are fluidically isolated from one another within the stem body.

[0197] Embodiment 23: The apparatus of any one of embodiments 1-22, wherein the interior flows paths are fluidically isolated from one another within the stem body, further comprising: a gas distributor comprising: a first surface comprising a plurality of inlets; and a second surface opposing the first surface, the second surface comprising a plurality of gas distribution ports; wherein: the stem body is coupled to the first surface of the gas distributor; the first interior flow path is fluidically connected with a first group of the gas distribution ports by way of a first outlet among the outlets of the stem body and a first inlet among the inlets of the gas distributor; and the second interior flow path is fluidically connected with a second group of the gas distribution ports by way of a second outlet among the outlets of the stem body and a second inlet among the inlets of the gas distributor, the gas distribution ports of the second group being distinct from the gas distribution ports of the first group.

[0198] Embodiment 24: The apparatus of embodiment 34, wherein the gas distributor is a showerhead pedestal of the semiconductor processing apparatus, the showerhead pedestal being configured to support a substrate at or near its periphery such that a backside of the substrate is substantially exposed to the gas distribution ports.

[0199] Embodiment 25: The apparatus of embodiment 23 or embodiment 24, further comprising: a process chamber configured to support a first portion of the stem body and the gas distributor therein, the process chamber comprising an opening through which a second portion of the stem body extends to expose the proximal end portion.

[0200] Embodiment 26: The apparatus of embodiment 25, further comprising: a pedestal configured to support a substrate within the process chamber, wherein the process chamber is configured to support the gas distributor over the pedestal such that the gas distribution ports

face the pedestal.

[0201] Unless otherwise specified, the illustrated embodiments are to be understood as providing example features of varying detail of some embodiments. Thus, unless otherwise specified, the features, components, modules, layers, films, regions, aspects, structures, etc. (hereinafter individually or collectively referred to as an “element” or “elements”), of the various illustrations may be otherwise combined, separated, interchanged, and/or rearranged without departing from the teachings of the disclosure.

[0202] The terminology used herein is for the purpose of describing some embodiments and is not intended to be limiting. As used herein, the singular forms, “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It is to be understood that the phrases “for each <item> of the one or more <items>,” “each <item> of the one or more <items>,” and/or the like, if used herein, are inclusive of both a single-item group and multiple-item groups, i.e., the phrase “for . . . each” is used in the sense that it is used in programming languages to refer to each item of whatever population of items is referenced. For example, if the population of items referenced is a single item, then “each” would refer to only that single item (despite dictionary definitions of “each” frequently defining the term to refer to “every one of two or more things”) and would not imply that there must be at least two of those items. Similarly, the term “set” or “subset” should not be viewed, in itself, as necessarily encompassing a plurality of items—it is to be understood that a set or a subset can encompass only one member or multiple members (unless the context indicates otherwise). The terms “comprises,” “comprising,” “includes,” and/or “including,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. It is also noted that, as used herein, the terms “substantially,” “about,” and other similar terms, are used as terms of approximation and not as terms of degree, and, as such, are utilized to account for inherent deviations in measured, calculated, and/or provided values that would be recognized by one of ordinary skill in the art. Accordingly, the term “substantially” as used herein, unless otherwise specified, means within 5% of a referenced value. For example, substantially perpendicular means within $\pm 5\%$ of parallel.

[0203] The use of cross-hatching and/or shading in the accompanying drawings is generally provided to clarify boundaries between adjacent elements. As such, neither the presence nor the absence of cross-hatching or shading conveys or indicates any preference or requirement for particular materials, material properties, dimensions, proportions, commonalities between

illustrated elements, and/or any other characteristic, attribute, property, etc., of the elements, unless specified. Further, in the accompanying drawings, the size and relative sizes of elements may be exaggerated for clarity and/or descriptive purposes. As such, the sizes and relative sizes of the respective elements are not necessarily limited to the sizes and relative sizes shown in the drawings. When an embodiment may be implemented differently, a specific process order may be performed differently from the described order. For example, two consecutively described processes may be performed substantially at the same time or performed in an order opposite to the described order.

[0204] When an element, such as a layer, is referred to as being “on,” “connected to,” or “coupled to” another element, it may be directly on, directly connected to, or directly coupled to the other element or at least one intervening element may be present. When, however, an element is referred to as being “directly on,” “directly connected to,” or “directly coupled to” another element, there are no intervening elements present. Other terms and/or phrases if used herein to describe a relationship between elements should be interpreted in a like fashion, such as “between” versus “directly between,” “adjacent” versus “directly adjacent,” “on” versus “directly on,” etc. Further, the term “connected” may refer to physical, electrical, and/or fluid connection. To this end, for the purposes of this disclosure, the phrase “fluidically connected” is used with respect to volumes, plenums, holes, etc., that may be connected to one another, either directly or via one or more intervening components or volumes, to form a fluidic connection, similar to how the phrase “electrically connected” is used with respect to components that are connected to form an electric connection. The phrase “fluidically interposed,” if used, may be used to refer to a component, volume, plenum, hole, etc., that is fluidically connected with at least two other components, volumes, plenums, holes, etc., such that fluid flowing from one of those other components, volumes, plenums, holes etc., to the other or another of those components, volumes, plenums, holes, etc., would first flow through the “fluidically interposed” component before reaching that other or another of those components, volumes, plenums, holes, etc.. For example, if a pump is fluidically interposed between a reservoir and an outlet, fluid flowing from the reservoir to the outlet would first flow through the pump before reaching the outlet. The phrase “fluidically adjacent,” if used, refers to placement of a fluidic element relative to another fluidic element such that no potential structures fluidically are interposed between the two elements that might potentially interrupt fluid flow between the two fluidic elements. For example, in a flow path having a first valve, a second valve, and a third valve arranged sequentially therealong, the first valve would be fluidically adjacent to the second valve, the second valve fluidically adjacent to both the first

and third valves, and the third valve fluidically adjacent to the second valve.

[0205] For the purposes of this disclosure, “at least one of X, Y, . . . , and Z” and “at least one selected from the group consisting of X, Y, . . . , and Z” may be construed as X only, Y only, . . . , Z only, or any combination of two or more of X, Y, . . . , and Z, such as, for instance, XYZ, XYY, YZ, and ZZ. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0206] Although the terms “first,” “second,” “third,” etc., may be used herein to describe various elements, these elements should not be limited by these terms. These terms are used to distinguish one element from another element. Thus, a first element discussed below could be termed a second element without departing from the teachings of the disclosure. To this end, use of such identifiers, e.g., “a first element,” should not be read as suggesting, implicitly or inherently, that there is necessarily another instance, e.g., “a second element.” Further, the use, if any, of ordinal indicators, such as (a), (b), (c), . . . , or (1), (2), (3), . . . , or the like, in this disclosure and accompanying claims, is to be understood as not conveying any particular order or sequence, except to the extent that such an order or sequence is explicitly indicated. For example, if there are three steps labeled (i), (ii), and (iii), it is to be understood that these steps may be performed in any order (or even concurrently, if not otherwise contraindicated), unless indicated otherwise. For example, if step (ii) involves the handling of an element that is created in step (i), then step (ii) may be viewed as happening at some point after step (i). In a similar manner, if step (i) involves the handling of an element that is created in step (ii), the reverse is to be understood.

[0207] Spatially relative terms, such as “beneath,” “below,” “under,” “lower,” “above,” “upper,” “over,” “higher,” “side” (e.g., as in “sidewall”), and the like, may be used herein for descriptive purposes, and, thereby, to describe one element’s spatial relationship to at least one other element as illustrated in the drawings. Spatially relative terms are intended to encompass different orientations of an apparatus in use, operation, and/or manufacture in addition to the orientation depicted in the drawings. For example, if the apparatus in the drawings is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” or “over” the other elements or features. Thus, the term “below” can encompass both an orientation of above and below. Furthermore, the apparatus may be otherwise oriented (e.g., rotated 90 degrees or at other orientations), and, as such, the spatially relative descriptors used herein interpreted accordingly.

[0208] The term “between,” as used herein and when used with a range of values, is to be understood, unless otherwise indicated, as being inclusive of the start and end values of that

range. For example, between 1 and 5 is to be understood as inclusive of the numbers 1, 2, 3, 4, and 5, not just the numbers 2, 3, and 4.

[0209] As used herein, the phrase “operatively connected” is to be understood as referring to a state in which two components and/or systems are connected, either directly or indirectly, such that, for example, at least one component or system can control the other. For instance, a controller may be described as being operatively connected with (or to) a resistive heating unit, which is inclusive of the controller being connected with a sub-controller of the resistive heating unit that is electrically connected with a relay that is configured to controllably connect or disconnect the resistive heating unit with a power source that is capable of providing an amount of power that is able to power the resistive heating unit so as to generate a desired degree of heating. The controller itself likely will not supply such power directly to the resistive heating unit due to the current(s) involved, but it is to be understood that the controller is nonetheless operatively connected with the resistive heating unit.

[0210] As used herein, the singular forms, “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It is also to be understood that the phrases “for each <item> of the one or more <items>,” “each <item> of the one or more <items>,” and/or the like, if used herein, are inclusive of both a single-item group and multiple-item groups, i.e., the phrase “for . . . each” is used in the sense that it is used in programming languages to refer to each item of whatever population of items is referenced. For example, if the population of items referenced is a single item, then “each” would refer to only that single item (despite dictionary definitions of “each” frequently defining the term to refer to “every one of two or more things”) and would not imply that there must be at least two of those items. Similarly, the term “set” or “subset” should not be viewed, in itself, as necessarily encompassing a plurality of items—it is to be understood that a set or a subset can encompass only one member or multiple members (unless the context indicates otherwise). In addition, the terms “comprises,” “comprising,” “includes,” and/or “including,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0211] Various embodiments are described herein with reference to sectional views, isometric views, perspective views, plan views, and/or exploded illustrations that are schematic depictions of idealized embodiments and/or intermediate structures. As such, variations from the shapes of the illustrations as a result of, for example, manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments disclosed herein should not be construed

as limited to the particular illustrated shapes of regions, but are to include deviations in shapes that result from, for instance, manufacturing. To this end, regions illustrated in the drawings may be schematic in nature and shapes of these regions may not reflect the actual shapes of regions of a device, and, as such, are not intended to be limiting.

[0212] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure is a part. Terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and are not to be interpreted in an idealized or overly formal sense, unless expressly so defined herein.

[0213] As customary in the field, some embodiments are described and illustrated in the accompanying drawings in terms of functional blocks, units, and/or modules. Those skilled in the art will appreciate that these blocks, units, and/or modules are physically implemented by electronic (or optical) circuits, such as logic circuits, discrete components, microprocessors, hard-wired circuits, memory elements, wiring connections, and the like, which may be formed using semiconductor-based fabrication techniques or other manufacturing technologies. In the case of the blocks, units, and/or modules being implemented by microprocessors or other similar hardware, they may be programmed and controlled using software (e.g., microcode) to perform various functions discussed herein and may optionally be driven by firmware and/or software. It is also contemplated that each block, unit, and/or module may be implemented by dedicated hardware, or as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. Also, each block, unit, and/or module of some embodiments may be physically separated into two or more interacting and discrete blocks, units, and/or modules without departing from the inventive concepts. Further, the blocks, units, and/or modules of some embodiments may be physically combined into more complex blocks, units, and/or modules without departing from the teachings of the disclosure.

[0214] Although the foregoing embodiments have been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. It should be noted that there are many alternative ways of implementing the processes, systems, and apparatuses of the disclosed embodiments. Accordingly, embodiments are to be considered as illustrative and not as restrictive, and embodiments are not to be limited to the details given herein.

CLAIMS

What is claimed is:

1. An apparatus for semiconductor processing, the apparatus comprising:
a stem body comprising:
a proximal end portion comprising a plurality of inlets, each of the inlets being distinct from one another and configured to receive a corresponding one or more gases; and
a distal end portion arranged opposite the proximal end portion along a longitudinal axis of the stem body, the distal end portion being configured to interface with a gas distributor of a semiconductor processing apparatus, the distal end portion comprising a plurality of outlets, at least one of the outlets being distinct from at least another one of the outlets; and
a plurality of interior flow paths comprising a first interior flow path and a second interior flow path, each of the interior flow paths extending between a corresponding inlet among the inlets and at least one corresponding outlet among the outlets such that the interior flow paths are distinct from one another, at least one of the interior flow paths comprising one or more structures configured to induce turbulent flow along the longitudinal axis of the stem body in response to a flow of the corresponding one or more gases.
2. The apparatus of claim 1, wherein, in a section of the stem body, the second interior flow path encircles the first interior flow path along the longitudinal axis and/or the first interior flow path is concentrically aligned with the second interior flow path.
3. The apparatus of claim 1, wherein:
the one or more structures of the interior flow paths comprise one or more first structures;
each of the first structures comprises:
an internal passageway extending along the longitudinal axis of the stem body and defining a respective first portion of the first interior flow path; and
a plurality of first channels extending along the longitudinal axis of the stem body and defining respective first portions of the second interior flow path, the first channels being circumferentially spaced apart from one another about the longitudinal axis of the stem body.
4. The apparatus of claim 3, wherein each internal passageway is coaxially aligned with the longitudinal axis of the stem body and in fluidic communication with one another.

5. The apparatus of claim 3, wherein:

the one or more structures of the interior flow paths comprises multiple first structures axially arranged along the longitudinal axis of the stem body; and

first central axes of the first channels of one first structure among the multiple first structures are circumferentially offset from second central axes of the first channels of another first structure among the multiple first structures.

6. The apparatus of claim 3, wherein:

the stem body comprises a sleeve and a core;

the sleeve comprises an interior that contacts an exterior of the core;

each internal passageway extends in a central portion of the core; and

each first channel is formed as a respective first recess in the exterior of the core such that a corresponding first longitudinal passageway is formed, at least in part, by that respective first channel and a corresponding portion of the interior of the sleeve.

7. The apparatus of claim 6, wherein:

the sleeve comprises a first opening and a second opening in fluidic communication with the first opening, the first opening being closer to the proximal end portion than the second opening;

the core comprises a first end portion and a second end portion, the first end portion being closer to the proximal end portion than the second end portion;

the second end portion extends out of the second opening and comprises the at least one corresponding outlet of the first interior flow path, the second end portion having a section of reduced cross-sectional area in a plane perpendicular to the longitudinal axis; and

the at least one corresponding outlet of the second interior flow path is defined, at least in part, by an exterior of the section of reduced cross-sectional area of the second end portion and a corresponding portion of the interior of the sleeve.

8. The apparatus of claim 6, wherein:

the stem body further comprises an extension;

a first part of the extension defines the proximal end portion;

a second part of the extension interfaces with each of the sleeve and the core; and

the extension comprises:

a first interior supply path in fluidic communication with at least one of the internal

passageways of the first structures and defining a portion of the first interior flow path; and
a second interior supply path in fluidic communication with at least one of the first channels of the first structures and defining a portion of the second interior flow path.

9. The apparatus of claim 8, wherein at least one of a central axis of the first interior supply path and a central axis of the second interior supply path is offset from the longitudinal axis of the stem body.

10. The apparatus of claim 9, wherein each of the central axis of the first interior supply path and the central axis of the second interior supply path is offset from the longitudinal axis of the stem body.

11. The apparatus of claim 1, wherein the interior flows paths are fluidically isolated from one another within the stem body.

12. The apparatus of claim 1,
wherein the apparatus comprises the gas distributor, which comprises:
a first surface comprising a plurality of inlets; and
a second surface opposing the first surface, the second surface comprising a plurality of gas distribution ports; and
wherein:
the stem body is coupled to the first surface of the gas distributor;
the first interior flow path is in fluidic communication with a first group of the gas distribution ports by way of a first outlet among the outlets of the stem body and a first inlet among the inlets of the gas distributor; and
the second interior flow path is in fluidic communication with a second group of the gas distribution ports by way of a second outlet among the outlets of the stem body and a second inlet among the inlets of the gas distributor, the gas distribution ports of the second group being distinct from the gas distribution ports of the first group.

13. The apparatus of claim 12, further comprising a process chamber configured to support a first portion of the stem body and the gas distributor therein, the process chamber comprising an opening through which a second portion of the stem body extends to expose the proximal end portion.

14. The apparatus of claim 13, further comprising:
a pedestal configured to support a substrate within the process chamber,
wherein the process chamber is configured to support the gas distributor over the
pedestal such that the gas distribution ports face the pedestal.