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 dilution gases may be delivered to (and, thereby, from) one or more second zones, and one or more precursor gases and 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.

**[0102]** 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

flow paths traversing second inlet 1801, at least one of elongated holes 1813, 1815, 1817, 1819, 1821, 1833, 1835, 1837, 1839, 1841, 1847, and 1849, at least one of blind cavities 1547, 1573a, 1573b, 1577a, 1577b, 1581a, 1581b, 1585a, 1585b, 1589a, and 1589b, and at least one of through-holes 1527, 1531, 1535, 1539, and 1543. Thus, at least some of the gas distribution flow paths formed between first inlets 1701 and 1702 and the gas distribution ports of zone 713, the first gas distribution ports of zone 711, and the third gas distribution ports of zone 715 may share a coincident portion, such as within a passageway of first inlet 1701 or second inlet 1702. Similarly, at least some of the gas distribution flow paths formed between second inlet 1801 and the second gas distribution ports of zone 711 and the fourth gas distribution ports of zone 715 may share a coincident portion, such as within a passageway of second inlet 1801. An illustrative gas distribution flow path will be described in more detail in association with FIG. 19.

**[0182]** Adverting to FIG. 19, gas distribution flow path 1901 may supply $n^{th}$ gas distribution port 707n of, for instance, zone 715_2 with the one or more second gases received at second inlet 1801. In this manner, gas distribution flow path 1901 may flow from second inlet 1801 to elongated hole 1813, which allows the one or more second gases of gas distribution flow path 1901 to flow into blind cavity 1573a, which may function as an intake plenum and as a distribution plenum. As pressure builds in blind cavity 1573a, the one or more second gases of gas distribution flow path 1901 may be forced into through-hole 1527 and expelled via $n^{th}$ gas distribution port 707n to an area proximate a substrate during a deposition operation. Each of the other gas distribution ports among gas distribution ports 707 may be similarly supplied with the one or more first gases or the one or more second gases via corresponding gas distribution flow paths routing between one of first inlets 1701 and 1702 or second inlet 1801 and a corresponding one of the other gas distribution ports among gas distribution ports 707.

**[0183]** In various implementations, the gas distribution flow paths extending from first inlets 1701 and 1702 may be fluidically separated or isolated from the gas distribution flow paths extending from second inlet 1801 in an interior of showerhead pedestal 700. However, as previously mentioned, given that at least one gap may exist between one or more of upper and inner surfaces 703a and 703b of outer wall 703 and fourth and third surfaces 701d and 701c of main body 701, some of blind cavities 1549a–1589a and 1549b–1589b may include a plug (e.g., plug 1903) filling respective portions of, for instance, their distal end portions interfacing with outer wall 703 to further discourage gas from leaking between adjacent blind cavities, which may be configured to flow different gases from one another. For instance, one or more of blind

to a power source (e.g., power supply 2237 of FIG. 22) to controllably heat showerhead pedestal 700 and a substrate (such as wafer 2301 of FIG. 23) supported thereon. Heating loop 2001 may be resistively heated and thermally coupled to (e.g., in thermal contact with) main body 701. Further, heating loop 2001 may be disposed on and/or at least partially embedded within main body 701. For example, main body 701 may include at least one slot (or groove) 2009 in second surface 701b that is configured to receive a lower section of heating loop 2001.

**[0191]** As depicted in FIGS. 7B, 19, and 20, first portion 2001a of heating loop 2001 may enter main body 701 through hollow 733 in stem 705, bend to form second portion 2001b in a first outer peripheral region of main body 701, bend to form third portion 2001c in a first inner peripheral region of main body 701, bend to form fourth portion 2001d in an inner central region of main body 701, bend to form fifth portion 2001e in a second inner peripheral region of main body 701, bend to form a sixth portion 2001f in a second outer peripheral region of main body 701, and bend to form seventh portion 2001g exiting main body 701 through hollow 733 in stem 705. It is noted that first distal end 2001h of heating loop 2001 may be coupled to a power source and second distal end 2001i of heating loop 2001 may be coupled to a refence level, such as ground, floating ground, or another relatively low potential.

**[0192]** In some implementations, second and sixth portions 2001b and 2001f of heating loop 2001 may follow generally "C" shaped paths in corresponding outer peripheral regions of main body 701 that face one another. Third and fifth portions 2001c and 2001e of heating loop 2001 may also follow generally "C" shaped paths, but in corresponding inner peripheral regions of main body 701 that face one another. The corresponding outer peripheral regions of main body 701 may at least partially surround the corresponding inner peripheral regions of main body 701. Fourth portion 2001d of heating loop 2001 may follow a generally "Ω" shaped path in the inner central region of main body 701 adjacent to distal end 801 of stem body 731, e.g., adjacent to first and second inlets 1701, 1702, and 1801. In addition, the inner central region of main body 701 may be at least partially surrounded by the corresponding inner peripheral regions of main body 701. It is also noted that first and seventh portions 2001a and 2001g of heating loop 2001 may generally extend in an axial direction along central axis 717 of showerhead pedestal 700, whereas second to sixth portions 2001b to 2001f of heating loop 2001 may generally meander in a transverse plane at (or substantially at) a first distance $H_{1905}$ (see FIG. 19) from second surface 701b of main body 701. It is contemplated, however, that any other suitable path through and/or about main body 701 may be utilized.

an input conduit 2219 of exhaust system 2215. Coolant, e.g., liquid coolant, for heat exchanger 2213 may enter heat exchanger 2213 at second inlet 2221, follow coolant path 2223, and exit heat exchanger 2213 via second outlet 2225. The coolant may be water or any other suitable coolant, e.g., Freon. In one embodiment, the coolant may be facilities provided water. After exiting heat exchanger 2213 via second outlet 2225, the coolant may be compressed and recirculated back into heat exchanger 2213 in a closed-loop coolant system, but embodiments are not limited thereto. In this manner, the CDA flow from outlet portion 2217 of cooling loop 2205 may be cooled via heat exchanger 2213 and expelled via exhaust system 2215.

**[0206]** Although heat exchanger 2213 has been described as a gas-to-liquid heat exchanger, embodiments are not limited thereto. For instance, heat exchanger 2213 may be configured as a gas-to-gas heat exchanger, and, in such cases, aspects of second inlet 2221 and second outlet 2225 of heat exchanger 2213 reconfigured to correspondingly interface with a suitable cooling source and a suitable effluent waste, recycling, and/or feedback system. When configured as a gas-to-gas heat exchanger, the cooling fluid may be, for instance, a source of atmospheric air, argon, helium, nitrogen, hydrogen, CDA, and/or the like.

**[0207]** According to some embodiments, the CDA output from heat exchanger 2213 may be about or slightly above ambient temperature and pressure. In some implementations, the temperature of the CDA output from heat exchanger 2213 may be greater than or equal to about 20$^{o}$C and less than or equal to about 65$^{o}$C. It is noted, however, that heat exchanger 2213 may be configured to ensure that any residual heat in the effluent from cooling loop 2205 can be held within output-based environmental regulatory limits.

**[0208]** Conduit 2219 may be coupled to conduit 2227, which may be part of (or fluidically connected to) exhaust system 2215. In some implementations, exhaust system 2215 may be a scrubbed exhaust system. As such, any environmentally controlled components, constituents, by-products, etc., of the effluent from the first outlet of heat exchanger 2213 may be scrubbed via scrubber 2229 along with other effluents 2231 of the substrate processing system and/or ambient environment.

**[0209]** According to some embodiments, heating of gas distributor 2207 may be provided by thermal management system (or system) 2200 via heating loop 2233, such as heating loop 2001 described in association with FIG. 20. In this manner, input portion 2235 of heating loop 2233 may receive power from power supply 2237, and output portion 2239 of heating loop 2233

**CLAIMS**

1. An apparatus comprising:

a main body comprising:

a first surface;

a second surface opposing the first surface in a first direction;

a first gas passage fluidically connected to one or more first gas inlets and extending in a second direction between the first surface and the second surface, the second direction being transverse to the first direction;

a second gas passage extending in the second direction and spaced apart from the first gas passage in a third direction transverse to each of the first direction and the second direction, the second gas passage being fluidically connected to one or more second gas inlets;

first gas distribution ports fluidically connected to the first gas passage; and

second gas distribution ports fluidically connected to the second gas passage,

wherein:

at least one of the one or more first gas inlets is fluidically separate from the one or more second gas inlets within the main body; and

at least some of the first gas distribution ports and at least some of the second gas distribution ports are arranged in an alternating manner with respect to the second direction.

2. The apparatus of claim 1, wherein, when viewed in the first direction, the at least some of the first gas distribution ports and the at least some of the second gas distribution ports are arranged between the first gas passage and the second gas passage.

3. The apparatus of either claim 1 or claim 2, wherein the first gas distribution ports and the second gas distribution ports form respective openings in the first surface.

4. The apparatus of claim 1 or claim 2, further comprising:

a third gas passage fluidically connected to the one or more first gas inlets and extending in the second direction between the first surface and the second surface, the third gas passage being adjacent to the second gas passage in the third direction;

third gas distribution ports fluidically connected to the third gas passage; and

fourth gas distribution ports fluidically connected to the second gas passage,

wherein:

at least some of the third gas distribution ports and at least some of the fourth gas distribution ports are arranged in an alternating manner with respect to the second direction; and

when viewed in the first direction, the at least some of the third gas distribution ports and the at least some of the fourth gas distribution ports are arranged between the second gas passage and the third gas passage.

5. The apparatus of claim 4, wherein the third gas distribution ports and the fourth gas distribution ports form respective openings in the first surface.

6. The apparatus of claim 1 or claim 2, further comprising:

one or more fourth gas passages fluidically connected to the one or more first gas inlets and extending in the second direction between the first surface and the second surface, the one or more fourth gas passages being adjacent to the first gas passage in a fourth direction opposite the third direction;

a fifth gas passage fluidically connected to the one or more second gas inlets and extending in the second direction between the first surface and the second surface, the fifth gas passage being adjacent to the one or more fourth gas passages in the fourth direction;

fifth gas distribution ports fluidically connected to the one or more fourth gas passages; and

sixth gas distribution ports fluidically connected to the fifth gas passage,

wherein:

a first some of the fifth gas distribution ports are arranged with respect to the second direction;

a second some of the fifth gas distribution ports and at least some of the sixth

gas distribution ports are arranged in an alternating manner with respect to the second direction; and

when viewed in the first direction, the second some of the fifth gas distribution ports and the at least some of the sixth gas distribution ports are arranged between the fifth gas passage and the one or more fourth gas passages.

7. The apparatus of claim 1, wherein:

the first surface comprises a plurality of gas distribution ports;

the plurality gas distribution ports comprise the first gas distribution ports and the second gas distribution ports;

the first gas passage and the second gas passage are among a plurality of gas passages extending in the second direction between the first surface and the second surface; and

each of the gas passages is fluidically connected to one or more gas distribution ports among the gas distribution ports of the first surface.

8. The apparatus of claim 7, wherein respective cross-sectional areas of the gas passages in a plane perpendicular to the second direction are substantially equivalent.

9. The apparatus of claim 7, wherein a cross-sectional area of at least one of the gas passages in a plane perpendicular to the second direction is different from a cross-sectional area of at least another one of the gas passages in the plane perpendicular to the second direction.

10. The apparatus of any one of claims 7–9, wherein corresponding pitches between adjacent gas passages among the gas passages are substantially equivalent.

11. The apparatus of claim 1, wherein:

the at least some of the first gas distribution ports are fluidically connected to the first gas passage via first gas risers;

the at least some of the second gas distribution ports are fluidically connected to the second gas passage via second gas risers;

the first gas risers extend in a fifth direction transverse to each of the first direction, the second direction, the third direction, and a fourth direction opposite the third direction; and

the second gas risers extend in a sixth direction transverse to each of the first direction, the second direction, the third direction, the fourth direction, and the fifth direction.

12. The apparatus of claims 1, further comprising:

an outer wall surrounding the main body,

wherein the main body further comprises:

a third surface extending between the first surface and the second surface, the third surface facing an inner surface of the outer wall;

a plurality of first blind cavities recessed into the third surface and arranged about a perimeter of the main body, the first blind cavities defining portions of a first plenum volume within the main body; and

a plurality of second blind cavities recessed into the third surface and arranged about a perimeter of the main body, the second blind cavities defining portions of a second plenum volume within the main body,

wherein:

the first plenum volume and the second plenum volume are fluidically separate within the main body;

a first distal end of the first gas passage is fluidically connected to a first blind cavity among the first blind cavities; and

a first distal end of the second gas passage is fluidically connected to a second blind cavity among the second blind cavities.

13. The apparatus of claim 12, wherein at least some of the first blind cavities alternate about the perimeter of the main body with at least some of the second blind cavities.

14. The apparatus of claim 12, wherein:

each first blind cavity among the first blind cavities has a first opening area facing the inner surface of the outer wall; and

the first opening areas are substantially equivalent to one another or at least one of the first opening areas is different from at least another one of the first opening areas.

15. The apparatus of claim 14, wherein:

each second blind cavity among the second blind cavities has a second opening area facing the inner surface of the outer wall; and

the second opening areas are substantially equivalent to one another or at least one of the second opening areas is different from at least another one of the second opening areas.

16. The apparatus of claim 15, wherein the first opening areas and the second opening areas are equivalent.

17. The apparatus of claim 12, further comprising:

a plurality of plugs respectively filling portions of only corresponding first blind cavities among the first blind cavities or only corresponding second blind cavities among the second blind cavities.

18. The apparatus of claim 12, further comprising:

a plurality of first elongated holes in the main body that extend radially from a first central region of the main body, each of the first elongated holes having:

a corresponding proximal end fluidically connected to at least one of the one or more first gas inlets; and

a corresponding distal end fluidically connected to a first blind cavity among the first blind cavities;

a plurality of second elongated holes in the main body that extend radially from a second central region of the main body, each of the second elongated holes having:

a corresponding proximal end fluidically connected to at least one of the one or more gas second inlets; and

a corresponding distal end fluidically connected to a second blind cavity among the second blind cavities.

19. The apparatus of claim 18, wherein the first central region is arranged between the second central region and a periphery of the main body.

20. The apparatus of either claim 18 or claim 19, wherein:

each of the first elongated holes extends in a first planar region of the main body;

each of the second elongated holes extends in a second planar region of the main body different from the first planar region of the main body; and

the second planar region is closer to the first surface of the main body than the first planar region.

21. The apparatus of claim 1, further comprising:

a cooling conduit in thermal contact with the main body, the cooling conduit having an inlet being configured to receive clean dry air (CDA) at a first temperature and an outlet being configured to output the CDA at a second temperature different from the first temperature,

wherein the main body comprises a first groove recessed into the second surface, a portion of the cooling conduit extending within the first groove.

22. The apparatus of claim 21, further comprising:

a first cap structure enclosing the cooling conduit in the first groove in a compressed state.

23. The apparatus of either claim 21 or claim 22, wherein the cooling conduit is formed of stainless steel.

24. The apparatus of claim 21 or claim 22, wherein the cooling conduit is sized to enable a flow rate of CDA up to about 140 standard liters per minute with a Reynolds number greater than about 2000.

25. The apparatus of claim 21 or claim 22, further comprising:

a resistive heating element,

wherein the main body further comprises a second groove recessed into the second surface, a portion of the resistive heating element extending within the second groove.

26. The apparatus of claim 1 or claim 2, further comprising:

a process chamber configured to support the main body therein,

wherein the main body forms a portion of a showerhead.

27. The apparatus of claim 26, wherein:

the first gas distribution ports and the second gas distribution ports are among a plurality of gas distribution ports forming openings in the first surface of the main body; and

the showerhead is a showerhead pedestal configured to support a substrate thereover such that a majority of a backside of the substrate is exposed to the plurality of gas distribution ports.

28. The apparatus of claim 1 or claim 2, wherein the main body is formed of an aluminum alloy.