

SHOWERHEAD HAVING MULTIPLE PLENUMS AND A FACEPLATE WITH A CENTRAL GAS DISTRIBUTION PORT

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 their entireties and for all purposes.

BACKGROUND

[0002] Semiconductor manufacturing processes often occur within a chamber in which a semiconductor wafer or semiconductor wafers are supported on pedestals during wafer processing operations. Such a pedestal may be positioned underneath a corresponding gas distribution system, e.g., a showerhead, that may be used to distribute process gases across the exposed side of a semiconductor wafer supported by the pedestal. Such showerheads may, in some cases, include active cooling features. Disclosed herein are new showerhead designs that offer more effective and efficient cooling performance as compared to more conventional designs.

SUMMARY

[0003] 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.

[0004] The present disclosure relates to a showerhead for a semiconductor processing system. The showerhead may include a faceplate with two or more sets of gas distribution ports to distribute two or more process gases, respectively, across an exposed side of a semiconductor wafer supported by the pedestal. The showerhead may further include two or more inlets configured to receive a flow of two or more process gasses, respectively. The showerhead may further include two or more plenums fluidically interposed between the corresponding two or more inlets and the sets of gas distribution ports.

[0005] The showerhead may have a first gas passage including a first inlet. The showerhead may further include a second gas passage isolated from the first gas passage within the showerhead and having a second inlet separate from the first inlet and located along a center

axis of that showerhead. The showerhead may further include a faceplate surface facing the corresponding wafer support, with the faceplate surface having a plurality of first gas distribution ports distributed across the faceplate surface and fluidically connected with the first gas passage within the showerhead. The faceplate surface may further include a plurality of second gas distribution ports distributed across the faceplate surface and fluidically connected with the second gas passage within the showerhead. The showerhead may further include a first center-fed plenum fluidically interposed between the first gas passage and the first gas distribution ports, with the first center-fed plenum spaced from the faceplate surface by a first distance. The showerhead may further include a second center-fed plenum fluidically interposed between the second gas passage and the second gas distribution ports, with the second center-fed plenum spaced from the faceplate surface by a second distance that is shorter than the first distance. The first gas distribution ports may include a center first gas distribution port located at a center of the faceplate surface.

[0006] In some implementations, the showerhead may further include an injector body having the first gas passage with the first inlet and the second gas passage with the second inlet. The showerhead may further include a showerhead assembly attached to the injector body. The showerhead assembly may include the first center-fed plenum having a first outer edge region and a first center region located radially inward from the first outer edge region. The first center-fed plenum may be fluidically connected with the first gas passage in the injector body, and the first center-fed plenum may have an upper surface and a lower surface facing the upper surface. The showerhead assembly may further include a plurality of first columns located in the first center-fed plenum and extending between the upper surface of the first center-fed plenum and the lower surface of the first center-fed plenum. The showerhead assembly may include the second center-fed plenum having a second outer edge region and a second center region located radially inward from the second outer edge region. The second center-fed plenum may be fluidically connected with the second gas passage in the injector body, and the second center-fed plenum may have an upper surface and a lower surface facing the upper surface of the second center-fed plenum. The showerhead assembly may include a plurality of second columns located in the second center-fed plenum and extending between the upper surface of the second center-fed plenum and the lower surface of the second center-fed plenum. The second columns may include a plurality of conduits fluidically interposed between the first center-fed plenum and the first gas distribution ports.

[0007] In some implementations, the first center-fed plenum may have an inner perimeter surface facing radially inward and defining an interior of the first center-fed plenum, and the first columns may be distributed through the interior of the first center-fed plenum.

[0008] In some implementations, the second center-fed plenum may have an inner perimeter surface facing radially inward and defining an interior of the second center-fed plenum, and the second columns may be distributed through the interior of the second center-fed plenum.

[0009] In some implementations, the showerhead assembly may further include a top layer having a center conduit extending along the center axis of the corresponding showerhead. The center conduit may include a first plenum inlet fluidically interposed between the first gas passage in the injector body and the first center-fed plenum. The center conduit may further include a second plenum inlet fluidically interposed between the second gas passage in the injector body and the second center-fed plenum. The showerhead assembly may further include a bottom layer having the first gas distribution ports in the faceplate surface of the corresponding showerhead with the first gas distribution ports fluidically connected with the conduits in the second columns located in the second center-fed plenum. The bottom layer may further include the second gas distribution ports in the faceplate surface of the corresponding showerhead with the second gas distribution ports fluidically connected with the second center-fed plenum. The showerhead assembly may further include a middle layer located between the top layer and the bottom layer. The middle layer may include a plurality of first holes fluidically interposed between an interior of the first center-fed plenum and the conduits in the second columns located in the second center-fed plenum. The middle layer may further have one or more second holes fluidically interposed between the second plenum inlet and an interior of the second center-fed plenum.

[0010] In some implementations, each of the first columns may be bonded to or unitary with the top layer and the middle layer, thereby forming a contiguous load path between the upper surface of the first center-fed plenum and the lower surface of the first center-fed plenum and stiffening the showerhead in a region of the first center-fed plenum.

[0011] In some implementations, each of the second columns may be bonded to or unitary with the middle layer and the bottom layer, thereby forming a contiguous load path between the upper surface of the second center-fed plenum and the lower surface of the second center-fed plenum and stiffening the showerhead in a region of the second center-fed plenum.

[0012] In some implementations, the top layer, the middle layer, and the bottom layer may be diffusion bonded to one another, and the top layer may be sealingly engaged to the injector body.

[0013] In some implementations, the top layer may be configured to sealingly engage with the injector body. The middle layer may be configured to sealingly engage with the top layer to define the first center-fed plenum, with each of the first columns forming a tensile and compressive load path between the upper surface of the first center-fed plenum and the lower surface of the first center-fed plenum. The bottom layer may be configured to sealingly engage with the middle layer to define the second center-fed plenum, with each of the second columns forming a tensile and compressive load path between the upper surface of the second center-fed plenum and the lower surface of the second center-fed plenum.

[0014] In some implementations, the first holes in the middle layer may be distributed across the middle layer and may include a center first hole located at a center of the middle layer along the center axis of the corresponding showerhead. The lower surface of the first center-fed plenum may include one or more grooves fluidically interposed between the interior of the first center-fed plenum and the center first hole located at the center of the middle layer.

[0015] In some implementations, the second plenum inlet may have an upper segment fluidically connected with second gas passage in the injector body. The second plenum inlet may further include one or more lower segments fluidically interposed between the upper segment and a corresponding one or more of the second holes in the middle layer. The second plenum inlet may have an end sealingly engaged with the middle layer at the lower surface of the first center-fed plenum to separate the one or more lower segments of the second plenum inlet and the corresponding one or more second holes in the middle layer from the one or more grooves and the interior of the first center-fed plenum.

[0016] In some implementations, the one or more grooves may include two linear grooves fluidically connected with a pair of diametrically opposite sides of the center first hole located at the center of the middle layer.

[0017] In some implementations, the one or more lower segments of the second plenum inlet comprise two reniform apertures fluidically interposed between the upper segment of the second plenum inlet and the corresponding one or more second holes in the middle layer.

[0018] In some implementations, the one or more second holes in the middle layer may be two reniform holes fluidically interposed between the two reniform apertures of the second plenum inlet and the interior of the second center-fed plenum.

[0019] In some implementations, the two reniform holes in the middle layer may be fluidically isolated from the center first hole in the middle layer and the one or more grooves in the lower surface of the first center-fed plenum within the corresponding showerhead.

[0020] In some implementations, the showerhead assembly may further include a cooling layer mounted to one or more of the top layer, the middle layer, and the bottom layer. The cooling layer may include one or more coolant passages configured to be caused to circulate a coolant that removes heat from the cooling layer.

[0021] In some implementations, the showerhead assembly may further include a heating layer mounted to one or more of the top layer, the middle layer, and the bottom layer. The heating layer may include one or more heating elements configured to be caused to transfer heat to the heating layer.

[0022] In some implementations, each of the first columns may be a cylindrical body having a curved lateral surface configured to flow a first gas around the corresponding first column and distribute the first gas throughout the first center-fed plenum.

[0023] In some implementations, each of the second columns may be a cylindrical body having a curved lateral surface configured to flow a second gas around the corresponding second column and distribute the second gas throughout the second center-fed plenum.

[0024] In some implementations, at least a portion of the one or more showerheads may be made of a metal, an alloy, a ceramic, or a plastic.

[0025] An apparatus may include one or more showerheads each positioned above a corresponding wafer support located in an interior volume of a processing chamber. The showerhead may have a first gas passage including a first inlet. The showerhead may further include a second gas passage isolated from the first gas passage within the showerhead and having a second inlet separate from the first inlet and located along a center axis of that showerhead. The showerhead may further include a faceplate surface facing the corresponding wafer support, with the faceplate surface having a plurality of first gas distribution ports distributed across the faceplate surface and fluidically connected with the first gas passage within the showerhead. The faceplate surface may further include a plurality of second gas distribution ports distributed across the faceplate surface and fluidically connected with the second gas passage within the showerhead. The showerhead may further include a first center-fed plenum fluidically interposed between the first gas passage and the first gas distribution ports, with the first center-fed plenum spaced from the faceplate surface by a first distance. The showerhead may further include a second center-fed plenum fluidically interposed between the second gas passage and the second gas distribution ports, with the second center-fed plenum spaced from the faceplate surface by a second distance that is shorter than the first distance. The first gas distribution ports may include a center first gas distribution port located at a center of the faceplate surface. The apparatus may further include one or more gas curtain outlets

configured to provide a circumferential gas curtain encircling the faceplate surface of that showerhead.

[0026] In some implementations, each of the one or more gas curtain outlets may include a curtain gas passage configured to be caused to flow one or more curtain gases. A semiconductor processing system may include a carrier assembly having a top plate with a chamber surface facing the interior volume of the processing chamber, with the chamber surface having two or more rims defining two or more corresponding holes in the chamber surface. The carrier assembly may be configured to engage two or more of the showerheads and hold each of the showerheads within a corresponding one of the holes in the chamber surface at a fixed position relative to the carrier assembly and define an annular gap between the corresponding rim of the top plate and an outer edge region of the faceplate surface of the corresponding showerhead. The annular gap may be fluidically connected with the curtain gas passage and may be configured to be caused to flow the one or more curtain gases along a flow path having an annular cross-section encircling the faceplate surface of the showerhead.

[0027] In some implementations, the chamber surface of the top plate may have an outer perimeter region and a center spaced radially inward from the outer perimeter region. The annular gap may have a portion located in the outer perimeter region of the chamber surface. The chamber surface of the top plate may include a plurality of purge ports distributed across the chamber surface and may be configured to be caused to flow one or more curtain gases. One or more portions of the outer perimeter region of the chamber surface having the annular gap may not include the purge ports.

[0028] In some implementations, each of the showerheads may include an annular flange with a mounting surface facing radially outward relative to the center axis of that showerhead; and the carrier assembly may include a locator surface facing radially inward toward the center axis of the corresponding showerhead, each of the locator surfaces may be configured to engage the mounting surface of the corresponding showerhead and hold the outer edge region of the faceplate surface of that showerhead in a fixed position relative to the corresponding rim and provide the annular gap between that rim and the outer edge region of the faceplate surface of that showerhead.

[0029] In some implementations, the curtain gas passage may include a constriction having a predetermined length and fluidically connected with the annular gap. The curtain gas passage may further include a chamber portion fluidically connected with the constriction and having a volume based on a flow requirement to act as a manifold for uniform distribution of the curtain gas.

[0030] In some implementations, each of the showerheads may include a showerhead constriction surface facing radially outward relative to the center axis of that showerhead. The carrier assembly may include a carrier constriction surface for each of the showerhead constriction surfaces. Each of the carrier constriction surfaces may face radially inward toward the center axis of the corresponding showerhead. Each of the carrier constriction surfaces may be spaced radially outward from the showerhead constriction surface of the corresponding showerhead to define the constriction fluidically connected with the annular gap.

[0031] In some implementations, the apparatus may further include a gas distribution system including a plurality of valves controllable to selectively cause one or more process gases from a plurality of different gas sources connectable to the gas distribution system to be flowed to the one or more showerheads.

[0032] Further areas of applicability of the present disclosure will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0034] FIG. 1 depicts a perspective cutaway view of an example semiconductor processing system having multiple example showerheads, illustrating one showerhead with a gas curtain outlet configured to be caused to flow a curtain gas encircling a faceplate surface of the showerhead.

[0035] FIG. 2 depicts a cross-sectional view of one of the showerheads of FIG. 1, showing the curtain gas surrounding a wafer support supporting a substrate in substrate processing region within an interior volume of a processing chamber.

[0036] FIG. 3 depicts an enlarged cross-sectional view of the showerhead of FIG. 1 as taken along line A-A, illustrating the showerhead having an injector body including a first gas passage.

[0037] FIG. 4 depicts a perspective cutaway view of the showerhead of FIG. 1 as taken along line B-B, showing a center first gas distribution port of a plurality of first gas distribution ports located at a center of a bottom layer.

[0038] FIG. 5 depicts a cross-sectional view of the showerhead of FIG. 3 as taken along line A-A, illustrating the injector body having a second gas passage.

[0039] FIG. 6A depicts an enlarged cutaway perspective view of the showerhead of FIG. 4 as taken along line C-C, showing a second plenum inlet in a center conduit of a top layer.

[0040] FIG. 6B depicts an enlarged cutaway perspective view of the showerhead of FIG. 6A without the second plenum inlet in the center conduit of the top layer.

[0041] FIG. 7 is an enlarged view of Region 1 of the showerhead of FIG. 2, illustrating an implementation of the showerhead and a top plate defining a gas curtain outlet.

[0042] FIG. 8 depicts an enlarged perspective cutaway view of the showerhead of FIG. 2, showing the showerhead including a cooling layer.

[0043] FIG. 9 depicts an enlarged perspective cutaway view of the showerhead of FIG. 2, showing the showerhead including a heating layer.

DETAILED DESCRIPTION

[0044] Referring to FIG. 1, a semiconductor processing system 100 (e.g., a chemical deposition system, an etching treatment system, etc.) includes one or more showerheads 102 configured to be caused to flow one or more process gases during one or more semiconductor processing operations (e.g., a deposition process, a preparation process, a heat treatment process, etc.). The semiconductor processing system 100 further includes a processing chamber 104 with an interior volume 106 and one or more wafer supports 108 positioned within the interior volume 106 and configured to support corresponding substrates 110. Each of the one or more showerheads 102 (e.g., a flush-mount showerhead, etc.) is positioned above the corresponding one or more wafer supports 108 and used to flow one or more process gases onto the substrate 110 during the one or more semiconductor processing operations conducted within the interior volume 106 of the processing chamber 104. The semiconductor processing system 100 further includes a gas distribution system 112 having a plurality of valves 114 controllable to selectively cause the one or more process gases from a plurality of different gas sources 116 connectable to the gas distribution system 112 to be flowed through one or more flow paths of each showerhead 102 and onto the corresponding substrate 110 within the interior volume 106 of the processing chamber 104.

[0045] In some conventional multi-plenum showerheads, each plenum may be fed one or more process gases by a gas inlet that is centrally located or by one or more gas inlets that are located about the periphery of that plenum. However, implementing a dual-plenum showerhead in which both plenums are center-fed may introduce complications. For example, in such showerheads, the one gas inlet may be coaxial with another gas inlet. However, the innermost gas inlet may, for example, block the outer gas inlet from reaching a port located at the center

of the showerhead, thereby preventing the outer gas inlet from being able to deliver process gas from a center-located port on the underside of the showerhead. The absence of gas distribution ports in the center region of the faceplate may deplete one or more process gases from one or more locations on the substrate 110 (e.g., a center portion of the substrate 110) and cause a corresponding non-uniformity in the substrate 110 at those locations. Furthermore, certain semiconductor processing systems can include a module with multiple showerheads, and the process gases from one showerhead may contaminate one or more wafers positioned below the other corresponding showerheads.

[0046] As described in detail below, each one of the showerheads 102 has a first gas passage 118 and a second gas passage 120 isolated from the first gas passage 118 within that showerhead 102. The first gas passage 118 includes a first inlet 122, and the second gas passage 120 includes a second inlet 124 separate from the first inlet 122. In this implementation, both of the first inlet 122 and the second inlet 124 are located within a center region 126 of that showerhead 102. Each one of the showerheads 102 further has a faceplate surface 128 facing the corresponding wafer support 108. The faceplate surface 128 includes a plurality of first gas distribution ports 130 distributed across the faceplate surface 128 and fluidically connected with the first gas passage 118 within the showerhead 102. The faceplate surface 128 further includes a plurality of second gas distribution ports 132 distributed across the faceplate surface 128 and fluidically connected with the second gas passage 120 within the showerhead 102. Each one of the showerheads 102 further has a first center-fed plenum 134 fluidically interposed between the first gas passage 118 and the first gas distribution ports 130, with the first center-fed plenum 134 being spaced from the faceplate surface 128 by a first distance D1 (FIG. 2). The first gas distribution ports 130 include a center first gas distribution port 136 located at a center location in the faceplate surface 128 and configured to flow one or more process gases to the substrate 110 to deposit a uniform film on the substrate 110. Each one of the showerheads 102 further has a second center-fed plenum 138 fluidically interposed between the second gas passage 120 and the second gas distribution ports 132, with the second center-fed plenum 138 being spaced from the faceplate surface 128 by a second distance D2 (FIG. 2) that is shorter than the first distance D1.

[0047] Referring to FIGS. 2 and 3, each showerhead 102 includes an injector body 140 having the first gas passage 118 with the first inlet 122 and the second gas passage 120 with the second inlet 124. In this implementation, the first gas passage 118 and the second gas passage 120 are located in a center region 126 of the corresponding showerhead 102. The first gas passage 118 may include two passage branches 142 (FIG. 3) fluidically connected with the first inlet 122.

These passage branches 142 may extend parallel to a center axis 144 of the showerhead 102 and be offset in opposite directions from the center axis 144. The second gas passage 120 may include a single center passage 146 fluidically connected with the second inlet 124 and extending along or collinear with the center axis 144. In other implementations, the first gas passage 118 may have more or fewer than two passage branches 142, and the second gas passage 120 may have more than the single center passage 146, with the first gas passage 118 and/or the second gas passage 120 having other suitable spatial arrangements relative to the center axis 144 and/or one another.

[0048] Referring to FIGS. 3 and 4, each showerhead 102 further includes a showerhead assembly 148 attached to the injector body 140. In this implementation, the showerhead assembly 148 includes a top layer 150 sealingly engaged with the injector body 140 (e.g., via one or more seals 152) and having a center conduit 154 extending along the center axis 144 of the corresponding showerhead 102. The center conduit 154 includes a first plenum inlet 156 (e.g., two obround or reniform openings 158, etc.). Fluidically interposed between the first gas passage 118 in the injector body 140 (e.g., the two passage branches 142 in the injector body 140) and the first center-fed plenum 134. (FIG. 3). In this implementation, the two obround or reniform openings 158 are spaced radially outward from the center axis 144. In other implementations, the first plenum inlet 156 in the center conduit 154 of the top layer 150 may have more or fewer than the two openings 158 with any other shape (e.g., one or more circular drilled holes) and arranged in other spatial arrangements relative to one another and/or the center axis 144. As described in detail below, the center conduit 154 further includes a second plenum inlet 160 fluidically interposed between the second gas passage 120 in the injector body 140 and the second center-fed plenum 138.

[0049] The showerhead assembly 148 further includes a middle layer 162 configured to sealingly engage with (e.g., via brazing, diffusion bonding, mechanical fastening, etc.) the top layer 150 to define the first center-fed plenum 134. The first center-fed plenum 134 is fluidically connected with the first gas passage 118 in the injector body 140 (e.g., the two passage branches 142 in the injector body 140) via the first plenum inlet 156 of the center conduit 154 in the top layer 150 (e.g., the two obround or reniform openings 158 in the top layer 150). As best shown in FIG. 2, the first center-fed plenum 134 has an inner perimeter surface 164 facing radially inward toward the center axis 144 and defining an interior 166 of the first center-fed plenum 134. The first center-fed plenum 134 includes a first outer edge region 168 and a first center region 170 located radially inward from the first outer edge region 168 and fluidically connected with the first plenum inlet 156 of the center conduit 154 in the

top layer 150. The first center-fed plenum 134 further has an upper surface 172 and a lower surface 174 facing the upper surface 172 of the first center-fed plenum 134. As described in detail below, the middle layer 162 has a plurality of first holes 176 (FIGS. 3 and 4) including a center first hole 178 located at a center of the middle layer 162 and extending along the center axis 144 of the corresponding showerhead 102. The showerhead assembly 148 further includes a plurality of conduits 180 in a plurality of second columns 182 including a center second column 184 located on the center axis 144 of the showerhead 102. The first holes 176 are fluidically interposed between the interior 166 of the first center-fed plenum 134 and the conduits 180 in the second columns 182, and the conduits 180 are fluidically interposed between the first holes 176 in the middle layer 162 and the first gas distribution ports 130 in the faceplate surface 128. Also, in this implementation, the center first hole 178 is fluidically interposed between the interior 166 of the first center-fed plenum 134 via one or more passages (e.g., grooves 186 depicted in FIGS. 4 and 6B and described in more detail below, etc.) and the conduit 180 in the center second column 184. The conduit 180 in the center second column 184 is fluidically interposed between the center first hole 178 in the middle layer 162 and the center first gas distribution port 136 in the faceplate surface 128. The center first gas distribution port 136 may be caused to flow one or more process gases to a center portion of the substrate 110 (e.g., to deposit a uniform film on the substrate, etc.). As described in detail below, the middle layer 162 further has one or more second holes 188 fluidically interposed between the second plenum inlet 160 of the center conduit 154 and the second center-fed plenum 138 in the showerhead assembly 148.

[0050] Referring to FIG. 4, the showerhead assembly 148 further includes a plurality of first columns 190 located in the first center-fed plenum 134 and extending between the upper surface 172 of the first center-fed plenum 134 and the lower surface 174 of the first center-fed plenum 134. The first columns 190 are distributed through the interior 166 of the first center-fed plenum 134. Each of the first columns 190 may form a tensile and compressive load path between the upper surface 172 of the first center-fed plenum 134 and the lower surface 174 of the first center-fed plenum 134. In this implementation, each of the first columns 190 is bonded to or unitary with the top layer 150 and the middle layer 162, thereby forming a contiguous load path between the upper surface 172 of the first center-fed plenum 134 and the lower surface 174 of the first center-fed plenum 134 and stiffening the showerhead 102 in the region of the first center-fed plenum 134. The first columns 190 may be uniformly distributed through the interior 166 of the first center-fed plenum 134 in a square grid pattern. In other implementations, the first columns 190 may be distributed through the interior 166 of the first

center-fed plenum 134 in a circular pattern, with the quantity of first columns 190 in each circle increasing in number with each larger-diameter circle of first columns 190. In still other implementations, the quantity of first columns 190 may remain constant in each larger-diameter circle of first columns 190. The first columns 190 may be uniformly or non-uniformly distributed through the interior 166 of the first center-fed plenum 134 in other patterns. Each one of the first columns 190 may have a cylindrical cross-section and a curved lateral surface configured to flow the first gas around the corresponding first column 190 and distribute the first gas throughout the first center-fed plenum 134. In other implementations, each first column 190 can have one or more planar surfaces, concave surfaces, and/or convex surfaces configured to direct a flow of the one or more process gases in the first center-fed plenum 134. In still other implementations, the showerhead assembly 148 may not include any of the first columns 190 located in the first center-fed plenum 134.

[0051] Referring to FIG. 5, the center conduit 154 in the top layer 150 further includes the second plenum inlet 160 (e.g., a split path) fluidically interposed between the second gas passage 120 in the injector body 140 (e.g., the single center passage 146 in the injector body 140) and the second center-fed plenum 138 in the showerhead assembly 148. In this implementation, the split path of the second plenum inlet 160 may include an upper segment 192 extending along the center axis 144 and fluidically connected with the second gas passage 120 in the injector body 140 (e.g., the single center passage 146 in the injector body 140). The split path may further include a lower segment 194 with two second plenum inlet branches 196 (e.g., two obround or reniform apertures 198 in FIG. 6A, etc.) spaced radially outward from the center axis 144 and fluidically interposed between the upper segment 192 of the second plenum inlet 160 and an interior 200 of the second center-fed plenum 138 via the one or more second holes 188 (e.g., two obround or reniform holes 202 in FIG. 6B) in the middle layer 162. The two reniform holes 202 in the middle layer 162 are fluidically isolated from the center first hole 178 in the middle layer 162 and the one or more grooves 186 in the lower surface 174 of the first center-fed plenum 134 within the corresponding showerhead 102. In one implementation, the one or more grooves 186 may include two linear grooves 186 fluidically connected with a pair of diametrically opposite sides of the center first hole 178 and extending radially outward from the center first hole 178. In other implementations, the one or more open-topped grooves 186 in the lower surface 174 may be omitted, and the middle layer 162 may have one or more other suitable passages fluidically interposed between the first center-fed plenum 134 and the center first hole 178 and fluidically isolated from the second plenum inlet 160. One non-limiting implementation of the one or more passages may include one or more

bores (e.g., circular bores, etc.) through the middle layer 162. In some implementations, the one or more bores may be drilled through the middle layer 162 and extend at any angle relative to any surface of the middle layer 162.

[0052] The showerhead assembly 148 further includes a bottom layer 204, with the middle layer 162 located between the top layer 150 and the bottom layer 204. The bottom layer 204 is configured to sealingly engage with (e.g., via brazing, diffusion bonding, mechanical fastening, etc.) the middle layer 162 to define the second center-fed plenum 138. The second center-fed plenum 138 is fluidically connected with the second gas passage 120 in the injector body 140 (e.g., the single center passage 146 in the injector body 140) via the second plenum inlet 160 of the center conduit 154 in the top layer 150 (e.g., the split path including the upper segment 192 and the lower segment 194 with the two second plenum inlet branches 196, such as two obround or reniform apertures 198). As best shown in FIG. 2, the second center-fed plenum 138 has an inner perimeter surface 206 facing radially inward and defining the interior 200 of the second center-fed plenum 138 via the second plenum inlet 160. The second center-fed plenum 138 includes a second outer edge region 208 and a second center region 209 located radially inward from the second outer edge region 208 and fluidically connected with the second plenum inlet 160 of the center conduit 154 in the top layer 150. The second center-fed plenum 138 further has an upper surface 210 and a lower surface 212 facing the upper surface 210 of the second center-fed plenum 138.

[0053] The showerhead assembly 148 further includes the second columns 182 (FIG. 5) located in the second center-fed plenum 138 and extending between the upper surface 210 of the second center-fed plenum 138 and the lower surface 212 of the second center-fed plenum 138. The second columns 182 are distributed through the interior 200 of the second center-fed plenum 138. Each of the second columns 182 may form a tensile and compressive load path between the upper surface 210 of the second center-fed plenum 138 and the lower surface 212 of the second center-fed plenum 138. In this implementation, each of the second columns 182 is bonded to or unitary with the middle layer 162 and the bottom layer 204, thereby forming a contiguous load path between the upper surface 210 of the second center-fed plenum 138 and the lower surface 212 of the second center-fed plenum 138 and stiffens the showerhead 102 in the region of the second center-fed plenum 138. The second columns 182 may be uniformly distributed through the interior 200 of the second center-fed plenum 138 in a square grid pattern. In other implementations, the second columns 182 may be distributed through the interior 200 of the second center-fed plenum 138 in a circular pattern, with the quantity of second columns 182 in each circle increasing in number with each larger-diameter circle of

second columns 182. In still other implementations, the quantity of second columns 182 may be constant with each larger-diameter circle of second columns 182. The second columns 182 may be uniformly or non-uniformly distributed through the interior 200 of the second center-fed plenum 138 in other patterns. Each second column 182 may have a cylindrical cross-section and a curved lateral surface configured to flow the second gas around the corresponding second column 182 and distribute the second gas throughout the second center-fed plenum 138. In other implementations, each second column 182 can have one or more planar surfaces, concave surfaces, and/or convex surfaces configured to direct a flow of the one or more process gases in the second center-fed plenum 138.

[0054] Referring back to FIGS. 3 and 4, while the conduits 180 in the second columns 182 are located in the second center-fed plenum 138, the conduits 180 in the second columns 182 are fluidically isolated from the second center-fed plenum 138 and fluidically interposed between the first center-fed plenum 134 and the first gas distribution ports 130 in the bottom layer 204. In this implementation, the first holes 176 in the middle layer 162 are fluidically interposed between the interior 166 of the first center-fed plenum 134 and the conduits 180 in the second columns 182. As best shown in FIGS. 4, 6A, and 6B, the first holes 176 are distributed across the middle layer 162 and include the center first hole 178, with the center first hole 178 being located at the center of the middle layer 162 and extending along the center axis 144 of the corresponding showerhead 102. The lower surface 174 of the first center-fed plenum 134 includes the one or more grooves 186 fluidically interposed between the interior 166 of the first center-fed plenum 134 and the center first hole 178.

[0055] The second plenum inlet 160 of the center conduit 154 in the top layer 150 has the upper segment 192 fluidically connected with second gas passage 120 in the injector body 140 (e.g., the single center passage 146 in the injector body 140). The second plenum inlet 160 further includes the lower segment 194 (e.g., including two second plenum inlet branches 196 such as two obround or reniform apertures 198) fluidically interposed between the upper segment 192 and one or more corresponding second holes 188 (e.g., two obround or reniform holes 202) in the middle layer 162. As shown in FIGS. 4 and 6A, the second plenum inlet 160 has an end portion 214 sealingly engaged with the middle layer 162 at the lower surface 174 of the first center-fed plenum 134 to fluidically separate the lower segment 194 of the second plenum inlet 160 and the second holes 188 in the middle layer 162 from the one or more grooves 186 and the interior 166 of the first center-fed plenum 134. The one or more second holes 188 in the middle layer 162 are fluidically interposed between the second plenum inlet 160 of the center conduit 154 and the interior 200 of the second center-fed plenum 138. The bottom layer 204

further includes the second gas distribution ports 132 in the faceplate surface 128 of the corresponding showerhead 102 with the second gas distribution ports 132 fluidically connected with the second center-fed plenum 138. In this implementation, the top layer 150, the middle layer 162, and the bottom layer 204 are plates made of an aluminum alloy (e.g., aluminum 6061) diffusion bonded to one another, which may increase an amount of contact between the surfaces of the corresponding layers to increase an amount of heat transferred between these layers and/or enhance a strength of the showerhead assembly 148. In other implementations, the top layer 150, the middle layer 162, and/or the bottom layer 204 may be layers made of other materials attached to one another by other fastening processes. For instance, other implementations of the top layer 150, the middle layer 162, and/or the bottom layer 204 may be made of other metals and their alloys diffusion bonded or brazed together (with or without a filler sheet layer of metal/alloy that bonds the plates together) by application of force at a suitable elevated temperature and provide the similar increased heat conduction through the showerhead assembly 148 and/or increased strength of the showerhead assembly 148. In still other implementations, the top layer 150, the middle layer 162, and/or the bottom layer 204 may be made of ceramics, plastics, etc. joined by other corresponding processes.

[0056] In other implementations, the second plenum inlet 160 of the center conduit 154 in the top layer 150 may have more or fewer segments than the upper segment and the lower segment. In implementations where the second plenum inlet 160 includes the lower segment 194, the lower segment 194 may have more than the two second plenum inlet branches 196 depicted in FIGS. 3 and 6A or a single passage. The second plenum inlet branches 196 and/or the single passage may have any suitable shape, including shapes different from obround or reniform, such as circular, oval, and polygonal.

[0057] Referring to FIGS. 1 and 2, the semiconductor processing system 100 further includes a carrier assembly 216 having a top plate 218 with a chamber surface 220 facing the interior volume 106 of the processing chamber 104. The chamber surface 220 has two or more rims 222 defining two or more corresponding holes 224 in the chamber surface 220. Each showerhead 102 further includes one or more gas curtain outlets 226 (i.e., an annular gap as described below or a series of holes distributed at the outlet of gas flow) configured to provide a circumferential gas curtain encircling the faceplate surface 128 of that showerhead 102. Each of the one or more gas curtain outlets 226 includes a curtain gas passage 228 configured to be caused to flow one or more curtain gases (e.g., one or more non-reactive gases, or one or more reactive gases to provide an edge flow of reactants to modify or manipulate edge uniformity on wafer, etc.). The carrier assembly 216 is configured to engage two or more showerheads

102 and hold each of the showerheads 102 within a corresponding one of the holes 224 in the chamber surface 220 at a fixed position relative to the carrier assembly 216 and define an annular gap 230 (FIG. 7) between the rim 222 of the top plate 218 and an outer edge region 232 of the faceplate surface 128 of the corresponding showerhead 102. The annular gap 230 is fluidically connected with the curtain gas passage 228 and configured to be caused to flow the one or more curtain gases along a flow path 234 having an annular cross-section (FIGS. 1 and 2) encircling the faceplate surface 128 of the showerhead 102. As shown in FIG. 1, the chamber surface 220 of the top plate 218 has an outer perimeter region 236 and a center 238 spaced radially inward from the outer perimeter region 236. The annular gap 230 has a portion 240 located in the outer perimeter region 236 of the chamber surface 220. The chamber surface 220 of the top plate 218 includes a plurality of purge ports 242 (FIG. 1) distributed across the chamber surface 220 and configured to be caused to flow one or more curtain gases. One or more portions of the outer perimeter region 236 of the chamber surface 220 having one or more of the annular gaps 230 do not include the purge ports 242.

[0058] Referring to FIG. 7, each of the showerheads 102 includes an annular flange 244 with a mounting surface 246 facing radially outward relative to the center axis 144 of that showerhead 102. The carrier assembly 216 includes a locator surface 248 facing radially inward toward the center axis 144 of the corresponding showerhead 102, each of the locator surfaces 248 is configured to engage the mounting surface 246 of the corresponding showerhead 102 and hold the outer edge region 232 of the faceplate surface 128 of that showerhead 102 in a fixed position relative to the corresponding rim 222 and provide the annular gap 230 between that rim 222 and the outer edge region 232 of the faceplate surface 128 of that showerhead 102. The curtain gas passage 228 includes a chamber portion 249 (i.e., a manifold) fluidically connected with a constriction 250, and the constriction 250 may have a predetermined length and be fluidically connected with the annular gap 230. The chamber portion 249 may have a volume based on a flow requirement to act as a manifold for uniform distribution.

[0059] In one implementation, the constriction 250 of the curtain gas passage 228 and the annular gap 230 have an average radial width, and a ratio of the predetermined length L of the constriction 250 to an average radial width W of the constriction 250 is above a minimum ratio threshold (e.g., at least 10:1, related to at least 10 units of length L of the constriction 250 to 1 unit length of the radial width of annular gap 230, etc.). In other implementations, the minimum ratio threshold may be less than 10:1. Each of the showerheads 102 includes a showerhead constriction surface 252 facing radially outward relative to the center axis 144 of that

showerhead 102. The carrier assembly 216 includes a carrier constriction surface 254 for each of the showerhead constriction surfaces 252, each of the carrier constriction surfaces 254 face radially inward toward the center axis 144 of the corresponding showerhead 102. Each of the carrier constriction surfaces 254 is spaced radially outward from the showerhead constriction surface 252 of the corresponding showerhead 102 to define the constriction 250 fluidically connected with the annular gap 230.

[0060] Referring to FIG. 8, the showerhead 102 may further include a cooling layer 256 mounted to one or more of the top layer 150, the middle layer 162, and the bottom layer 204. The cooling layer 256 includes one or more coolant passages 258 configured to be caused to circulate a coolant that removes heat from the cooling layer 256, which may in turn remove heat from the top layer 150, the middle layer 162, and/or the bottom layer 204 of the showerhead assembly 148 and remove heat from a center region of the substrate 110 to provide uniformity of the film (e.g., thickness) on the substrate 110.

[0061] Referring to FIG. 9, the showerhead 102 may further include a heating layer 260 mounted to one or more of the top layer 150, the middle layer 162, and the bottom layer 204. The heating layer 260 includes one or more heating elements 262 (e.g., a resistive heater wire, etc.) configured to be caused to generate and transfer heat to the heating layer 260, which may in turn transfer heat to one or more of the top layer 150, the middle layer 162, and the bottom layer 204 and facilitate with one or more semiconductor processing operations.

[0062] The semiconductor processing system 100 may further include a controller 264 configured to control the valves 114 of the gas distribution system 112 to cause the one or more process gases to be flowed into the processing chamber 104 during the semiconductor processing operations. Broadly speaking, the controller 264 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 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 the controller 264 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, with process gases flowing from the different gas sources 116 through the one or more showerheads 102 where material from the flow of process gases is deposited. The operational parameters may, in some examples, be part of a recipe defined by process

engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of the substrate 110.

[0063] The showerhead assemblies and the injector bodies discussed herein may be made using traditional, subtractive machining operations, such as milling, lathing, drilling, etc. Particular implementations that are disclosed or discussed may be particularly well-suited to such an approach and may allow a showerhead assembly and/or an injector body for such a showerhead to be manufactured in as few as two separate parts that may then be assembled together and welded so as to provide a showerhead with such integral and fluidically isolated coolant flow paths. While the showerhead discussed above may be made, as shown, in multiple conventionally machined or machinable components and assembled together, some or all of the discrete components discussed above may be made as a single, contiguous component, e.g., using additive manufacturing, such as 3D printing, and the use of additive manufacturing may allow some multi-part assemblies, e.g., the showerhead assembly 148, to be manufactured as a single part that has features identical or similar to the features of a multi-piece equivalent assembly.

[0064] In some implementations, the showerhead designs discussed herein may be made using additive manufacturing techniques such as selective laser melting (SLM) (which may be used to produce ceramic or silicon versions of such showerheads) or direct metal laser melting (DMLM) (which may be used to produce metal versions thereof). In particular, the showerhead designs discussed herein may be particularly suitable for being manufactured using laser powder-bed fusion (LPBF) additive manufacturing techniques, which may include manufacturing processes such as SLM, DMLM, SLS (selective laser sintering), and DMLS (direct metal laser sintering), all of which may be used to create metal-based components (and some of which, like SLS and SLM, may be used to create ceramic-based components). In most additive manufacturing processes, a part is manufactured by adding material to the part one horizontal layer at a time; such layers may be extremely thin, e.g., 0.02mm at a time is possible for DMLM parts. In DMLM, for example, a platen supporting a part is gradually lowered relative to a reference plane. The platen forms the “floor” of a cavity that is used to contain the part being manufactured. Each time the platen is lowered, powdered material is added to the cavity and then leveled so as to be level with the reference plane. A laser then scans across the reference plane and applies heat to the uppermost layer of powdered material in the regions where structure is desired, melting the powder granules to each other and to any underlying, previously fused structure. Once a particular layer is done, the platen may be lowered slightly,

a new layer of powdered material may be applied, and the laser melting process repeated. This process is repeated until the part is complete, at which point the cavity of the DMLM device will be filled with unmelted powdered material having buried within it the additively manufactured component.

[0065] For the purposes of this disclosure, the term “fluidically connected” is used with respect to volumes, plenums, holes, etc., that may be connected with one another, either directly or via one or more intervening components or volumes, in order to form a fluidic connection, similar to how the term “electrically connected” is used with respect to components that are connected together to form an electric connection. The term “fluidically interposed,” if used, may be used to refer to a component, volume, plenum, or hole that is fluidically connected with at least two other components, volumes, plenums, or holes such that fluid flowing from one of those other components, volumes, plenums, or holes to the other or another of those components, volumes, plenums, or holes would first flow through the “fluidically interposed” component before reaching that other or another of those components, volumes, plenums, or holes. For example, if a pump is fluidically interposed between a reservoir and an outlet, fluid that flowed from the reservoir to the outlet would first flow through the pump before reaching the outlet. The term “fluidically adjacent,” if used, refers to placement of a fluidic element relative to another fluidic element such that there are no potential structures fluidically 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 placed 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.

[0066] 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 to be inclusive of the numbers 1, 2, 3, 4, and 5, not just the numbers 2, 3, and 4.

[0067] The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to

mean a logical (A, B, or C), using a non-exclusive logical OR. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

CLAIMS

What is claimed is:

1. A showerhead for a semiconductor processing system, the showerhead comprising:

a first gas passage including a first inlet;

a second gas passage isolated from the first gas passage within the showerhead and including a second inlet separate from the first inlet and located along a center axis of the showerhead;

a faceplate surface including a plurality of first gas distribution ports distributed across the faceplate surface and fluidically connected with the first gas passage within the showerhead, and the faceplate surface further having a plurality of second gas distribution ports distributed across the faceplate surface and fluidically connected with the second gas passage within the showerhead;

a first center-fed plenum fluidically interposed between the first gas passage and the first gas distribution ports, the first center-fed plenum spaced from the faceplate surface by a first distance; and

a second center-fed plenum fluidically interposed between the second gas passage and the second gas distribution ports, the second center-fed plenum spaced from the faceplate surface by a second distance that is shorter than the first distance, wherein the first gas distribution ports include a center first gas distribution port located at a center of the faceplate surface.

2. The showerhead of claim 1, further comprising:

an injector body including the first gas passage with the first inlet and the second gas passage with the second inlet; and

a showerhead assembly attached to the injector body, the showerhead assembly including:

the first center-fed plenum having a first outer edge region and a first center region located radially inward from the first outer edge region, the first center-fed plenum fluidically connected with the first gas passage in the injector body, the first center-fed plenum having an upper surface and a lower surface facing the upper surface;

a plurality of first columns located in the first center-fed plenum and extending between the upper surface of the first center-fed plenum and the lower surface of the first center-fed plenum;

the second center-fed plenum having a second outer edge region and a second center region located radially inward from the second outer edge region, the second center-fed plenum fluidically connected with the second gas passage in the injector body, the second center-fed plenum having an upper surface and a lower surface facing the upper surface of the second center-fed plenum; and

a plurality of second columns located in the second center-fed plenum and extending between the upper surface of the second center-fed plenum and the lower surface of the second center-fed plenum, the second columns including a plurality of conduits fluidically interposed between the first center-fed plenum and the first gas distribution ports.

3. The showerhead of claim 2, wherein the first center-fed plenum has an inner perimeter surface facing radially inward and defining an interior of the first center-fed plenum, and the first columns are distributed through the interior of the first center-fed plenum.

4. The showerhead of claim 2, wherein the second center-fed plenum has an inner perimeter surface facing radially inward and defining an interior of the second center-fed plenum, and the second columns are distributed through the interior of the second center-fed plenum.

5. The showerhead of any of claims 2 to 4, wherein the showerhead assembly further comprises:

a top layer including a center conduit extending along the center axis of the showerhead, the center conduit comprising a first plenum inlet fluidically interposed between the first gas passage in the injector body and the first center-fed plenum, and the center conduit further comprising a second plenum inlet fluidically interposed between the second gas passage in the injector body and the second center-fed plenum;

a bottom layer including the first gas distribution ports in the faceplate surface of the showerhead with the first gas distribution ports fluidically connected with the conduits in the second columns located in the second center-fed plenum, and the bottom layer further including

the second gas distribution ports in the faceplate surface of the showerhead with the second gas distribution ports fluidically connected with the second center-fed plenum; and

a middle layer located between the top layer and the bottom layer, the middle layer including a plurality of first holes fluidically interposed between an interior of the first center-fed plenum and the conduits in the second columns located in the second center-fed plenum, and the middle layer further having one or more second holes fluidically interposed between the second plenum inlet and an interior of the second center-fed plenum.

6. The showerhead of claim 5, wherein each of the first columns is bonded to or unitary with the top layer and the middle layer, thereby forming a contiguous load path between the upper surface of the first center-fed plenum and the lower surface of the first center-fed plenum and stiffening the showerhead in a region of the first center-fed plenum.

7. The showerhead of claim 6, wherein each of the second columns is bonded to or unitary with the middle layer and the bottom layer, thereby forming a contiguous load path between the upper surface of the second center-fed plenum and the lower surface of the second center-fed plenum and stiffening the showerhead in a region of the second center-fed plenum.

8. The showerhead of claim 7, wherein the top layer, the middle layer, and the bottom layer are diffusion bonded to one another, and the top layer is sealingly engaged to the injector body.

9. The showerhead of claim 7, wherein:

the top layer is configured to sealingly engage with the injector body;

the middle layer is configured to sealingly engage with the top layer to define the first center-fed plenum, with each of the first columns forming a tensile and compressive load path between the upper surface of the first center-fed plenum and the lower surface of the first center-fed plenum; and

the bottom layer is configured to sealingly engage with the middle layer to define the second center-fed plenum, with each of the second columns forming a tensile and compressive load path between the upper surface of the second center-fed plenum and the lower surface of the second center-fed plenum.

10. The showerhead of claim 7, wherein:

the first holes in the middle layer are distributed across the middle layer and include a center first hole located at a center of the middle layer along the center axis of the showerhead; and

the lower surface of the first center-fed plenum includes one or more grooves fluidically interposed between the interior of the first center-fed plenum and the center first hole located at the center of the middle layer.

11. The showerhead of claim 10, wherein:

the second plenum inlet has an upper segment fluidically connected with second gas passage in the injector body, and the second plenum inlet further includes one or more lower segments fluidically interposed between the upper segment and a corresponding one or more of the second holes in the middle layer; and

the second plenum inlet has an end sealingly engaged with the middle layer at the lower surface of the first center-fed plenum to separate the one or more lower segments of the second plenum inlet and the corresponding one or more second holes in the middle layer from the one or more grooves and the interior of the first center-fed plenum.

12. The showerhead of any of claims 10 or 11, wherein the one or more grooves include two linear grooves fluidically connected with a pair of diametrically opposite sides of the center first hole located at the center of the middle layer.

13. The showerhead of claim 11, wherein the one or more lower segments of the second plenum inlet comprise two reniform apertures fluidically interposed between the upper segment of the second plenum inlet and the corresponding one or more second holes in the middle layer.

14. The showerhead of claim 13, wherein the one or more second holes in the middle layer comprise two reniform holes fluidically interposed between the two reniform apertures of the second plenum inlet and the interior of the second center-fed plenum.

15. The showerhead of claim 14, wherein the two reniform holes in the middle layer are fluidically isolated from the center first hole in the middle layer and the one or more grooves in the lower surface of the first center-fed plenum within the showerhead.

16. The showerhead of claim 5, wherein the showerhead assembly further comprises a cooling layer mounted to one or more of the top layer, the middle layer, and the bottom layer, and the cooling layer includes one or more coolant passages configured to be caused to circulate a coolant that removes heat from the cooling layer.

17. The showerhead of claim 5, wherein the showerhead assembly further comprises a heating layer mounted to one or more of the top layer, the middle layer, and the bottom layer, and the heating layer includes one or more heating elements configured to be caused to transfer heat to the heating layer.

18. The showerhead of claim 2, wherein each of the first columns is a cylindrical body having a curved lateral surface configured to flow a first gas around the corresponding first column and distribute the first gas throughout the first center-fed plenum.

19. The showerhead of claim 2, wherein each of the second columns is a cylindrical body having a curved lateral surface configured to flow a second gas around the corresponding second column and distribute the second gas throughout the second center-fed plenum.

20. The showerhead of claim 1, wherein at least a portion of showerhead is made of a metal, an alloy, a ceramic, or a plastic.

21. An apparatus comprising:
one or more of the showerheads of claim 1; and
one or more gas curtain outlets configured to provide a circumferential gas curtain encircling the faceplate surface of that showerhead.

22. The apparatus of claim 21, wherein:
each of the one or more gas curtain outlets comprises a curtain gas passage configured to be caused to flow one or more curtain gases;

the semiconductor processing system includes a carrier assembly having a top plate with a chamber surface facing an interior volume of a processing chamber, the chamber surface having two or more rims defining two or more corresponding holes in the chamber surface;

the carrier assembly is configured to engage two or more of the showerheads and hold each of the showerheads within a corresponding one of the holes in the chamber surface at a fixed position relative to the carrier assembly and define an annular gap between the corresponding rim of the top plate and an outer edge region of the faceplate surface of the corresponding showerhead; and

the annular gap is fluidically connected with the curtain gas passage and configured to be caused to flow the one or more curtain gases along a flow path having an annular cross-section encircling the faceplate surface of the showerhead.

23. The apparatus of claim 22, wherein:

the chamber surface of the top plate has an outer perimeter region and a center spaced radially inward from the outer perimeter region;

the annular gap has a portion located in the outer perimeter region of the chamber surface;

the chamber surface of the top plate includes a plurality of purge ports distributed across the chamber surface and configured to be caused to flow one or more curtain gases; and

one or more portions of the outer perimeter region of the chamber surface having the annular gap do not include the purge ports.

24. The apparatus of claim 23, wherein:

each of the showerheads includes an annular flange with a mounting surface facing radially outward relative to the center axis of that showerhead; and

the carrier assembly includes a locator surface facing radially inward toward the center axis of the corresponding showerhead, each of the locator surfaces is configured to engage the mounting surface of the corresponding showerhead and hold the outer edge region of the faceplate surface of that showerhead in a fixed position relative to the corresponding rim and provide the annular gap between that rim and the outer edge region of the faceplate surface of that showerhead.

25. The apparatus of claim 24, wherein:

the curtain gas passage includes a constriction having a predetermined length and fluidically connected with the annular gap; and

the curtain gas passage further includes a chamber portion fluidically connected with the constriction and having a volume based on a flow requirement to act as a manifold for uniform distribution of the curtain gas.

26. The apparatus of claim 25, wherein:

each of the showerheads includes a showerhead constriction surface facing radially outward relative to the center axis of that showerhead; and

the carrier assembly includes a carrier constriction surface for each of the showerhead constriction surfaces, each of the carrier constriction surfaces facing radially inward toward the center axis of the corresponding showerhead, and each of the carrier constriction surfaces is spaced radially outward from the showerhead constriction surface of the corresponding showerhead to define the constriction fluidically connected with the annular gap.

27. The apparatus of claim 22, further comprising a gas distribution system including a plurality of valves controllable to selectively cause one or more process gases from a plurality of different gas sources connectable to the gas distribution system to be flowed to the one or more showerheads.