

LOW-VOLUME SHOWERHEAD FOR SEMICONDUCTOR PROCESSING OPERATIONS

INCORPORATED BY REFERENCE

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

BACKGROUND

10 **[0002]** Semiconductor manufacturing processes often occur within a semiconductor process chamber in which a semiconductor wafer or semiconductor wafers are supported by a wafer support, such as a pedestal, and exposed to one or more process gases delivered via a showerhead.

[0003] Some semiconductor processes may be conformal in nature, e.g., deposition or etch processes in which different process gases are applied in alternating fashion to form (or etch away) multiple, thin layers of material. For example, atomic layer deposition (ALD) or atomic layer etch (ALE) both involve flowing different process gases in alternating fashion across a wafer. Each such pair of alternating gas flows may result in a layer of material being deposited (or etched) that is a single molecule thick, thereby allowing for layer stacks of a very uniform thickness to be built up layer by layer (or etched away layer by layer). When such process gases are both supplied via a common showerhead, the showerhead is purged of one process gas before the other process gas is flowed through the showerhead.

SUMMARY

[0004] 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.

[0005] These and other implementations are discussed in more detail below, although the disclosure will be understood to encompass at least the implementations listed in this section.

[0006] In some implementations, an apparatus may be provided that includes a showerhead having a first side having a plurality of gas distribution ports, a second side facing in an opposite direction from the first side of the showerhead and having a gas inlet, a gas distribution plenum, and a plurality of flow networks, each flow network comprising a corresponding spoke passage, a pair of corresponding first branch passages, a quartet of corresponding second branch passages, and a plurality of corresponding riser passages. The gas distribution ports may extend from the first side of the showerhead to the gas distribution plenum, the corresponding spoke passage, corresponding first branch passages, and corresponding second branch passages of each flow network may each include a respective inlet end and a respective outlet end, the respective inlet end of the corresponding spoke passage of each flow network may be connected to the gas inlet, the respective outlet end of the corresponding spoke passage of each flow network may be connected to the respective inlet ends of the corresponding first branch passages of that flow network, the respective outlet end of each of the corresponding first branch passages of each flow network may be connected to the respective inlet ends of two of the corresponding second branch passages of that flow network, each corresponding riser passage of each flow network may be connected to the gas distribution plenum, the corresponding riser passages of each flow network may include a first set of corresponding riser passages for that flow network and a second set of corresponding riser passages for that flow network, and the corresponding riser passages in the first set of corresponding riser passages for each flow network may each be positioned closer to a center of the gas inlet than the corresponding riser passages in the second set of corresponding riser passages for that flow network.

[0007] In some implementations, the plurality of flow networks may include a first set of flow networks and a second set of flow networks, the corresponding riser passages in the first set of corresponding riser passages for each flow network in the first set of flow networks may each be positioned at a first distance from a center of the gas inlet, the corresponding riser passages in the second set of corresponding riser passages for each

flow network in the first set of flow networks may each be positioned at a second distance from a center of the gas inlet, the corresponding riser passages in the first set of corresponding riser passages for each flow network in the second set of flow networks may each be positioned at a third distance from a center of the gas inlet, the corresponding riser passages in the second set of corresponding riser passages for each flow network in the second set of flow networks may each be positioned at a fourth distance from a center of the gas inlet, the first distance may be smaller than the second distance, the second distance may be smaller than the third distance, and the third distance may be smaller than the fourth distance.

10 **[0008]** In some such implementations, the flow networks in the second set of flow networks may each further include an octet of corresponding third branch passages, the corresponding third branch passages of each flow network in the second set of flow networks may each include a respective inlet end and a respective outlet end, and the respective outlet end of each of the corresponding second branch passages of each flow network in the second set of flow networks may be connected to the respective inlet ends of two of the corresponding third branch passages of that flow network.

15 **[0009]** In some further such implementations, each flow network in the first set of flow networks may have four riser passages in the plurality of corresponding riser passages for that flow network, each outlet end of each second branch passage of each flow network in the first set of flow networks may be connected to a different one of the four riser passages for that flow network, each flow network in the second set of flow networks may have eight riser passages in the plurality of corresponding riser passages for that flow network, and each outlet end of each third branch passage of each flow network in the second set of flow networks may be connected to a different one of the eight riser passages for that flow network.

20 **[0010]** In some such implementations, each corresponding second branch passage of each flow network in the first set of flow networks may extend along a corresponding first axis that passes through the gas inlet, and each corresponding second branch passage of each flow network in the second set of flow networks may extend along a corresponding second axis that passes through the gas inlet.

25 **[0011]** In some such implementations, each corresponding first axis may be coaxial with a different one of the corresponding second axes.

[0012] In some implementations, the corresponding spoke passages of the flow networks in the first set of flow networks may have larger respective minimum cross-sectional areas than the corresponding spoke passages of the flow networks in the second set of flow networks.

5 **[0013]** In some implementations, the corresponding spoke passages of at least some of the flow networks may be linear and may extend along corresponding axes extending radially outward from the gas inlet.

[0014] In some implementations, the corresponding second branch passages of at least some of the flow networks may be linear and may extend along corresponding
10 axes that pass through the gas inlet.

[0015] In some implementations, the corresponding first branch passages of at least some of the flow networks may follow arcuate paths.

[0016] In some implementations, the corresponding third branch passages of at least some of the flow networks may follow arcuate paths.

15 **[0017]** In some implementations, the apparatus may further include a plurality of baffle wall segments, and the baffle wall segments may be arranged in multiple concentric circular patterns within the gas distribution plenum and spaced apart from circumferentially adjoining baffle wall segments by corresponding radial gap passages.

[0018] In some implementations, at least some of the corresponding riser passages
20 may connect with the gas distribution plenum at respective corresponding ones of the corresponding radial gap passages.

[0019] In some implementations, the baffle wall segments may extend between a first side of the gas distribution plenum and a second side of the gas distribution plenum, the gas distribution plenum may be subdivided into multiple annular sub-plenums, each annular sub-plenum may be bounded by the baffle wall segments in
25 radially adjacent ones of the concentric circular patterns of baffle wall segments, and each annular sub-plenum may have a corresponding plenum thickness defined by a distance between the first side of the gas distribution plenum and the second side of the gas distribution plenum within that annular sub-plenum.

30 **[0020]** In some implementations, the corresponding plenum thicknesses of at least some of the annular sub-plenums may be different.

[0021] In some implementations, at least some of the radial gap passages may include recesses in one or both of the first side of the gas distribution plenum and the second side of the gas distribution plenum.

5 [0022] In some implementations, the recesses of at least some of the radial gap passages with associated recesses may extend into only one of the annular sub-plenums adjacent to the corresponding radial gap passages associated with those recesses.

[0023] In some implementations, the recesses of at least some of the radial gap passages including recesses may extend into both of the annular sub-plenums adjacent
10 to the corresponding radial gap passages associated with those recesses.

[0024] In some implementations, the corresponding first branch passages in the first set of flow networks may all be the same length.

[0025] In some implementations, the corresponding second branch passages in the first set of flow networks may all be the same length.

15 [0026] In some implementations, the corresponding third branch passages in the first set of flow networks may all be the same length.

[0027] In some implementations, the corresponding first branch passages and the corresponding second branch passages of each flow network may be arranged in a configuration having an “H” shape.

20 [0028] In some implementations, the corresponding first branch passages and the corresponding second branch passages of each flow network may be arranged in a configuration having an “H” shape, and each corresponding second branch passage of each flow network in the second set of flow networks and the corresponding third branch passages connected to that corresponding second branch passage may also be
25 arranged in a configuration having an “H” shape.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Reference to the following Figures is made in the discussion below; the Figures are not intended to be limiting in scope and are simply provided to facilitate the
30 discussion below.

[0030] FIG. 1 depicts a side view of an example of an ultra-low-volume showerhead.

- [0031] FIG. 2 depicts a section view of the showerhead of FIG. 1 along section line 2 in FIG. 1.
- [0032] FIG. 3 depicts a section view of the showerhead of FIG. 1 along section line 3 in FIG. 1.
- 5 [0033] FIG. 4 depicts a schematic of flow networks in the showerhead of FIG. 1.
- [0034] FIG. 5 depicts a schematic of alternative flow network configurations.
- [0035] FIG. 6 depicts a section view of the showerhead of FIG. 1 along section line 6 in FIG. 1.
- [0036] FIG. 7 depicts a section view of the showerhead of FIG. 1 along section line 7 in
10 FIG. 1.
- [0037] FIG. 8 depicts a section view of the showerhead of FIG. 1 along section line 8 in FIG. 1.
- [0038] FIG. 9 depicts the same view as FIG. 7, but with flow networks superimposed in dotted outlines and with section lines indicating half-section planes that correspond
15 to FIGS. 10 through 13.
- [0039] FIG. 10 depicts a section view of the showerhead of FIG. 9 along section line 10 in FIG. 9.
- [0040] FIG. 11 depicts a section view of the showerhead of FIG. 9 along section line 11 in FIG. 9.
- 20 [0041] FIG. 12 depicts a section view of the showerhead of FIG. 9 along section line 12 in FIG. 9.
- [0042] FIG. 13 depicts a section view of the showerhead of FIG. 9 along section line 13 in FIG. 9.
- [0043] FIG. 14 depicts an example of a recess in a gas distribution plenum of the
25 showerhead of FIG. 1.
- [0044] FIG. 15 depicts another example of a recess in the gas distribution plenum of the showerhead of FIG. 1.
- [0045] FIG. 16 depicts a schematic of a processing chamber having a showerhead as disclosed herein.
- 30 [0046] FIG. 17 depicts a schematic of a semiconductor processing tool that may include showerheads as discussed herein.

[0047] The above-described Figures are provided to facilitate understanding of the concepts discussed in this disclosure and are intended to be illustrative of some implementations that fall within the scope of this disclosure but are not intended to be limiting—implementations consistent with this disclosure and which are not depicted in the Figures are still considered to be within the scope of this disclosure.

DETAILED DESCRIPTION

[0048] In semiconductor processing systems with showerheads, a plenum of the showerhead serves to distribute the process gases delivered to the showerhead to a plurality of gas distribution ports located on the underside of the showerhead. The larger the plenum, the more volume there is for the process gas to diffuse into before flowing out of the gas distribution ports, thereby making the gas flow out of the gas distribution ports more uniform and evenly distributed. However, as the size of the plenum of a showerhead increases, the time it takes for the showerhead to reach steady state flow conditions will correspondingly increase. Moreover, the volume of process gas that must be flowed into the plenum in order to first start delivering process gas to the wafer also increases with increasing plenum size. In a system that is used to perform multi-layer conformal deposition or etch operations in which different process gases may be flowed in alternating fashion through the plenum of a showerhead, it is generally desirable to minimize the time it takes to complete a single flow cycle of a process gas, thereby minimizing the cycle time required to perform one complete, application of alternating process gases (including performing purge gas flow cycles in between the application of each process gas) and reducing the total amount of time it takes to perform a desired number of process cycles. To that end, the present application discloses geometries for new ultra-low volume (ULV) showerheads that may be used to deliver process gases in a generally uniform manner to a wafer. Such ULV showerheads may exhibit drastically reduced transient performance, e.g., the time necessary for gas flows through such showerheads to reach steady state and may help reduce the total amount of process gas needed for each process cycle.

[0049] FIG. 1 depicts a side view of an example of a ULV showerhead 110 (or just “showerhead 110”) in accordance with this disclosure. The showerhead 110 is, in this

case, formed by diffusion bonding, brazing, or otherwise joining multiple, machined metal layers together, e.g., multiple aluminum alloy plates that have various features machined into one or both sides thereof. In some implementations, at least the surfaces of the showerhead 110 that are exposed to process gases may be coated with a corrosion-resistant coating. The showerhead 110, in this example, has three layers 110a, 110b, and 110c. The showerhead 110 in this example may have a first side 112 that has a plurality of gas distribution ports (not shown, but see FIGS. 7 and 8) distributed thereacross and a second side 114 that may be configured with a gas inlet (not shown, but see FIG. 2) to receive one or more process gases during use; during use, the first side 112 of the showerhead is typically oriented towards a wafer being processed. FIG. 1 also depicts section lines that pass through various elevations of the showerhead 110 and that define sectioning planes for FIGS. 2, 3, 6, 7, and 8.

[0050] FIG. 2 depicts a section view of the layer 110a of the showerhead 110 along section line 2 in FIG. 1. The layer 110a may generally act as a back plate or cap for the layer 110b but may be equipped with a gas inlet 118; in this example, the gas inlet 118 has a smaller diameter 118a where it exits the layer 110a and then expands in diameter to a larger diameter 118b within the showerhead 110. The gas inlet 118 may, for example, be configured to receive one or more process gases that may be delivered to the showerhead 110 by a gas distribution system, such as one or more valves that may be connected with various gas sources and controlled to selectively provide various sets of one or more process gases to the showerhead during semiconductor processing operations. Also visible in FIG. 2 are bypass ports 134, which are discussed later herein.

[0051] FIG. 3 depicts a section view of the layer 110b of the showerhead 110 along section line 3 in FIG. 1. As can be seen in FIG. 3, the layer 110b of the showerhead 110 includes a plurality of flow networks 122, e.g., a first set of flow networks 122a and second set of flow networks 122b. FIG. 4 depicts schematics of the flow networks 122a and 122b of FIG. 3. In FIG. 4, various passages that form the flow networks 122a and 122b are represented by line segments having different line fonts, with each line segment (and passage) having a corresponding inlet end (marked “a”) and outlet end (marked “b”). It will be understood that while the passages (and the line segments representing the passages) are shown as being either straight or arcuate, other

implementations may feature passages that have different geometries. For example, the arcuate passages may, in some implementations, be replaced with linear passages.

[0052] As can be seen in FIG. 4, each flow network includes a spoke passage 136, a pair of first branch passages 138, a quartet of second branch passages 140, and a plurality of riser passages 132. The riser passages 132 may fluidically connect each flow network 122 to a gas distribution plenum (not shown, but see FIG. 7) of the showerhead 110.

[0053] The spoke passage 136 of each flow network 122 may have an inlet end that is connected to the gas inlet 118 and an outlet end that is connected to the inlet ends of two first branch passages 138 of that flow network 122. Similarly, the outlet end of each first branch passage 138 of each flow network 122 may be connected to the inlet ends of two second branch passages 140 of that flow network 122.

[0054] The riser passages 132 of each flow network may be divided into multiple sets of riser passages 132, e.g., a first set of riser passages 132 and a second set of riser passages 132. The riser passages 132 in the first set of riser passages 132 of each flow network 122 may each be positioned closer to a center of the gas inlet 118 than the riser passages 132 in the second set of riser passages 132 for that flow network 122. For example, in the flow network 122a, there are four riser passages 132, with two of the riser passages 132 (a first set of the riser passages 132) being positioned a first distance from the gas inlet 118 and the other two of the riser passages 132 (a second set of the riser passages 132) being positioned a second distance from the gas inlet 118 that is greater than the first distance, and with each such riser passage 132 being connected to the outlet end of a different one of the second branch passages 140 of that flow network. Similarly, in the flow network 122b, there are eight riser passages 132 that are divided into a first set of riser passages 132 (the four riser passages 132 that are closer to the gas inlet 118) that are positioned at a third distance from the gas inlet 118 that is greater than the second distance and a second set of riser passages 132 (the remaining four riser passages 132) that are positioned at a fourth distance from the gas inlet 118 that is greater than the third distance. The riser passages 132 in each flow network 122b are, in analogous fashion to the riser passages 132 of the flow network 122a, each connected to the outlet end of a different one of the third branch passages 142 of that flow network 122b.

[0055] It can also be seen from FIG. 4 that the flow networks 122 may have additional branch passages beyond the first branch passages 138 and the second branch passages 140. For example, the flow networks 122b can be seen to further include third branch passages 142, with the outlet end of each second branch passage 140 in each flow network 122b being connected to the inlet end of two third branch passages 142.

[0056] In some implementations, the first branch passages 138 of a particular set of flow networks 122 may all be the same length. Similarly, the second branch passages 140 of a particular set of flow networks 122 may also all be the same length and the third branch passages 142 (if present) of a particular set of flow networks 122 may also all be the same length. In such implementations, each spoke passage 136 may, in effect, connect with the first branch passages 138 at a location that is equidistantly spaced (in terms of fluid flow path length) between the outlet ends of those first branch passages 138. Similarly, each first branch passage 138 may connect with two second branch passages 140 at a location that is equidistantly spaced (again, in terms of fluid flow path length) between outlet ends of those second branch passages 140. And if the flow network 122 includes further branch passages, e.g., such as the third branch passages 142, each branch passage that connects with two other branch passages may connect with those two branch passages at a location that is equidistantly spaced from the outlet ends of those two branch passages. Such an arrangement may act to bifurcate the flow of gas at each such junction point, thereby recursively subdividing the gas flows provided to each spoke passage 136 of a given set of flow networks 122 until generally equally proportioned gas flows are delivered to each riser passage 132 of that set of flow networks 122.

[0057] It will be observed that flow networks 122 in each set of flow networks 122 may be arranged in a circular pattern around the gas inlet 118. In some implementations with multiple sets of flow networks 122, there may be equal numbers of flow networks 122 in each set of flow networks 122, and the flow networks in the sets of flow networks 122 may be arranged in a larger circular pattern that alternates instances of flow networks 122 from each set of flow networks 122. For example, in the depicted implementation, there is a circular array of eight flow networks 122 arranged in alternating fashion, e.g., 122a, 122b, 122a, 122b, 122a, 122b, 122a, and 122b.

[0058] It will also be observed that in some implementations, like in the depicted example, each pair of branch passages that connects with the outlet end of another passage and with the inlet ends of two pairs of other branch passages may form an “H” shape, e.g., the first branch passages 138 and the second branch passages 140 of each flow network 122 form an “H” shape. Similarly, each pair of second branch passages 140 connected with one of the first branch passages 138 of the flow networks 122b may connect with two pair of third branch passages 142 so as to also form “H” shapes.

[0059] In some implementations, as shown, for example, in the corresponding figures, each second branch passage 140 of each flow network 122 may extend along a corresponding axis that passes through the gas inlet 118, e.g., through a center axis of the gas inlet 118. For example, each second branch passage 140 of each flow network 122a may extend along a corresponding first axis that passes through the gas inlet 118, whereas each second branch passage 140 of each flow network 122b may extend along a corresponding second axis that passes through the gas inlet 118. In some such implementations, each second axis may be colinear or coaxial with a different one of the first axes.

[0060] It will be observed that the spoke passages 136 of at least some, if not all, of the flow networks 122 and at least some, if not all, of the second branch passages 140 of at least some, if not all, of the flow networks 122 may extend along axes that extend radially outward from the gas inlet 118, e.g., may be linear in nature. It may also be observed that the first branch passages 138 and the third branch passages 142 (if present) may, in some instances, follow arcuate paths, e.g., be arcuate in nature.

[0061] It will be understood, however, that the other configurations of flow networks that may be used in such showerheads may feature spoke passages 136 and branch passages that deviate from such arrangements. For example, as shown on the left side of FIG. 5, a flow network may have only linear branch passages (instead of arcuate first branch passages 138, for example, the flow network may have linear first branch passages 138). In another example, a flow network may have curved or non-linear spoke passages 136 and second branch passages 140, as shown at-right in FIG. 5.

[0062] FIG. 6 depicts a section view of the layer 110b of the showerhead 110 along section line 6 in FIG. 1. As can be seen, only the riser passages 132 and the bypass ports 134 are visible in this section view. Such passages may vertically route process gas that

has thus far been horizontally distributed by the remainder of the flow networks 122, e.g., directing such process gas into the gas distribution plenum.

[0063] FIG. 7 depicts a section view of the layer 110c of the showerhead 110 along section line 7 in FIG. 1. As can be seen in FIG. 7, the gas distribution plenum 116 is a large, circular volume that has a large number of baffle wall segments 160 distributed throughout.

[0064] The baffle wall segments 160 may be arranged in a plurality of concentric circular patterns, thereby subdividing the gas distribution plenum 116 into a plurality of annular sub-plenums (not called out, but see FIG. 10) that are concentric with one another and each bounded by the baffle wall segments 160 in radially adjacent ones of the concentric circular patterns of baffle wall segments 160. Each pair of circumferentially adjacent baffle wall segments 160 may be separated from one another by a corresponding radial gap passage 162 that allows process gas from one annular sub-plenum to flow into adjoining annular sub-plenums.

[0065] In some implementations, at least some or, in some cases, all of the riser passages 132 may connect to the gas distribution plenum 116 at locations that correspond with respective ones of the radial gap passages 162. For example, in the depicted implementation, each riser passage 132 connects to the gas distribution plenum 116 at a location centered over a corresponding one of the radial gap passages 162 such that the process gas that is introduced into the gas distribution plenum 116 by each riser passage 132 is caused to first flow along radial directions before spreading circumferentially within each annular sub-plenum.

[0066] The bypass ports 134 may be optionally provided as a way to provide a small amount of process gas to the middle of the gas distribution plenum 116, thereby allowing such process gas to bypass being flowed through the flow networks 122. Such bypass ports 134 may, in effect, act as small riser passages 132 that are not in any flow network and that may ensure that process gas is still delivered to the center of the gas distribution plenum 116.

[0067] FIG. 8 depicts a section view of the layer 110c of the showerhead 110 along section line 8 in FIG. 1. In this view, the gas distribution ports 120 that span between the first side 112 of the showerhead 110 and the gas distribution plenum 116 are clearly visible. While the gas distribution ports 120 are shown as being arranged in

circular patterns, other implementations may feature other arrangements or patterns of gas distribution ports 120, e.g., triangular or hexagonal lattice patterns, square or diamond patterns, etc.

[0068] FIG. 9 depicts the same view as FIG. 7, but with the flow networks 122

5 superimposed in dotted outlines and with section lines indicating half-section planes that correspond to FIGS. 10 through 13.

[0069] As can be seen in FIG. 10, the gas distribution plenum 116 (not called out, but generally consisting of the various elements shown in the upper half of layer 110c) is bounded above and below by a first side 164 and a second side 166 and subdivided into
10 the annular sub-plenums 168a–k by respective concentric rings of baffle wall segments 160a–j. The baffle wall segments 160 may, as indicated, span between the first side 164 of the gas distribution plenum 116 and the second side 166 of the gas distribution plenum 116, thereby providing structural reinforcement to the showerhead 110 but also providing for a large number of head conduction paths that may be used to
15 conduct heat from the first side 112 of the showerhead 110 to the second side 114 of the showerhead 110 (if desired, a cooler may be placed adjacent to the second side 114 of the showerhead 110 to remove heat from the showerhead 110, e.g., such as heat generated by the processing operations performed on a semiconductor wafer using the showerhead 110.

20 **[0070]** The annular sub-plenums 168a through 169k may have respective plenum thicknesses X_a through X_k that are each defined by a distance between the first side 164 of the gas distribution plenum 116 and the second side 166 of the gas distribution plenum 116 within the corresponding annular sub-plenum 168. As can be seen, there may be one or more annular sub-plenums 168 that have different plenum thicknesses.
25 For example, the plenum thicknesses may increase gradually (or occasionally remain constant) as one progresses radially inward from the outermost annular sub-plenum 168 until one reaches the riser passages 132 for the flow networks 122a, at which point the plenum thicknesses may remain relatively constant for one or more annular sub-plenums 168 before starting to decrease again in size towards the center of the
30 showerhead 110. Such variations in plenum thicknesses may be used to tune the radial gas flow within the gas distribution plenum 116. For example, by decreasing the plenum thickness in some annular sub-plenums 168, the flow resistance in such annular

sub-plenums 168 may be increased, thereby reducing the amount of radial gas flow through such annular sub-plenums. Conversely, increasing the plenum thickness in annular sub-plenums 168 will tend to have the opposite effect, e.g., encouraging additional radial gas flow through such annular sub-plenums.

5 **[0071]** FIGS. 11 through 13 depict additional section views of the showerhead 110 taken along other section lines, but are not discussed further herein since they simply provide further self-evident detail on the structures discussed above.

[0072] In addition to varying the plenum thicknesses of the annular sub-plenums 168, various other features of the showerhead 110 may also be adjusted in order to fine-tune the gas distribution/flow within the showerhead 110. For example, the minimum cross-sectional areas of the spoke passages (or any of the branch passages) for a give set of flow networks 122 may be increased or decreased in order to increase or decrease the flow conductance through that set of flow networks 122. For example, the minimum cross-sectional areas of the spoke passages 136 of the flow networks 122b may be caused to be larger, e.g., by increasing one or both of the spoke passage 136 width and height, than the minimum cross-sectional areas of the spoke passages 136 of the flow networks 122a. Such an arrangement may help offset a reduction in flow conductance in the spoke passages 136 of the flow networks 122b as compared to the flow conductance in the spoke passages 136 of the flow networks 122a that may arise due to the fact that the spoke passages 136 of the flow networks 122b are over twice as long as the spoke passages 136 of the flow networks 122a.

[0073] The radial gap passages 162 may also be designed to affect the flow of process gas within the showerhead 110. For example, some radial gap passages 162 may be configured to be narrower than other radial gap passages 162, thereby restricting the gas flow through such narrower radial gap passages 162 as compared with the gas flow through the wider radial gap passages 162. In some cases, the radial gap passages 162 for a given circular pattern of baffle wall segments 160 may vary in width. For example, the radial gap passages 162 in the fifth circular pattern of baffle wall segments 160 (with the outermost circular pattern of baffle wall segments 160 being the first circular pattern) include both wider-width radial gap passages 162 and narrower-width radial gap passages 162 arranged in alternating fashion. The narrower-width radial gap passages 162 in between the baffle wall segments 160 of the fifth circular pattern of

baffle wall segments 160 are, as can be seen, azimuthally aligned with the radial gap passages 162 in the sixth circular pattern of baffle wall segments 160, which are also radial gap passages 162 where riser passages 132 connect with the gas distribution plenum 116. Having the radial gap passages 162 in the fifth circular pattern of baffle wall segments 160 that are closest to such riser passages 132 be narrower in width reduces the flow conductance through such radial gap passages as compared with the larger-width radial gap passages 162 in the fifth circular pattern of baffle wall segments 160, thereby encouraging more of the gas that is flowed through the riser passages 132 located along the sixth circular pattern of baffle wall segments 160 to flow circumferentially or tangentially towards the larger-width radial gap passages 162 in the fifth circular pattern of baffle wall segments 160 instead of towards the narrower-width radial gap passages 162 (despite the narrower-width radial gap passages 162 being closer to such riser passages 132 than the wider-width radial gap passages 162 in the fifth circular pattern of baffle wall segments 160).

[0074] Other features that may be used to tune the gas flow within the gas distribution plenum 116 are recesses 172, which may generally be collocated with the radial gap passages 162, although the recesses 172 may not be used in some configurations or may, as shown, only be used for some (but not all) radial gap passages 162. Each recess 172 may be a shallow trough or groove that may be formed in the first side 164 of the gas distribution plenum 116 and/or the second side 166 of the gas distribution plenum 116, thereby creating, in effect, a small localized region through the corresponding radial gap passage 162 that has an increased plenum thickness as compared with the average or nominal plenum thickness of one or both annular sub-plenums 168 bracketing that radial gap passage 162. The recesses are visible in FIG. 7 as obround or rounded-corner rectangles collocated with various radial gap passages 162, and are also visible in the cross-sections of FIGS. 10 through 13 as well as in FIGS. 14 and 15.

[0075] For example, some of the recesses 172 may be configured, as shown in FIG. 14, to extend into both annular sub-plenums 168 that bound or are adjacent to the radial gap passages 162 at which such recesses 172 are located. As can be seen in FIG. 14, this may result in the depth of such a recess 172 relative to each annular sub-plenum 168 being different in cases where the neighboring annular sub-plenums 168

have different plenum thicknesses. In such cases, there may be a bias of gas flow into the annular sub-plenum 168 where the recess 172 depth is shallower.

[0076] In other instances, some of the recesses 172 may be configured, as shown in FIG. 15, to extend into only one of the annular sub-plenums 168 that bound the radial gap passages 162 at which such recesses 172 are located. As can be seen in FIG. 15, this may result in a recess 172 that is, in effect, completely open on one end (i.e., where the bottommost surface of the recess is coplanar with the first side 164 (or the second side 166, depending on which side of the gas distribution plenum 116 the recess is located) within one of the two neighboring annular sub-plenums 168. In such instances, if a riser passage 132 is located above such a recess 172, the gas that is flowed out of that riser passage 132 may, due to the relative lack of restriction at the “open” end of the recess 172, preferentially flow towards the open end of the recess 172. For example, for the radial gap passages 162 that are depicted in the ninth circular pattern of baffle wall segments 160, the gas that is delivered via the riser passages 132 that are located at such radial gap passages 162 may be biased to flow radially outward by such a recess 172 configuration.

[0077] It will be understood that while the depicted showerhead configuration exhibits a four-fold repeating symmetry, e.g., with four flow networks 122 in each set of flow networks, other implementations may feature three-fold, five-fold, six-fold, etc. repeating symmetry. For example, in some implementations, there may be five, six, seven, or eight flow networks 122 in a first set of flow networks, and a corresponding number of flow networks in a second set of flow networks. The angular spacing between the spoke passages 136 in such implementations may be adjusted accordingly, e.g., be set to a value equal to 360° divided by the total number of flow networks 122 (or spoke passages 136). For example, the angular spacing may be 45° for a showerhead with eight flow networks but 30° for a showerhead with twelve flow networks.

[0078] It will also be appreciated that the number of branch passages that may be used for each flow network may also be varied depending on the implementation. While the depicted implementation features flow networks with first- and second-order branch passages, as well as flow networks with first-, second-, and third-order branch

passages, other implementations, may feature additional levels of branching passages, each level generally configured similarly to the examples discussed herein.

[0079] Further variants of the showerheads discussed herein may also include changes in the number and/or size of gas distribution ports, as well as the manner in which the gas distribution ports are arranged. In some instances, the gas distribution ports for different regions of the showerhead may be of different sizes and/or densities, while in other implementations, the sizes of the gas distribution ports may be kept uniform. It will also be recognized that the distribution of baffle wall segments 160 in the gas distribution plenum 116 may also be adjusted or varied, e.g., to have more or fewer such baffle wall segments in particular circular patterns of baffle wall segments or to have more or fewer circular patterns of baffle wall segments 160 (and thus also more or fewer annular sub-plenums 168).

[0080] Showerheads constructed according to the design paradigms discussed above may provide gas delivery for wafer processing that features very low transient response time. For example, such showerheads may have a total internal volume (excluding the portion of the gas inlet above the spoke passages 136 and the excluding the gas distribution ports themselves) that is on the order of 210 milliliters (but which may have gas distribution ports distributed across a 300mm diameter or larger arear). Moreover, such showerheads, due to the radial symmetry that can be incorporated into the design, may offer high uniformity in terms of process gas delivery.

[0081] To give a sense of scale, the annular sub-plenums may, in some cases, have plenum thicknesses that are on the order of 3 to 4 mm maximum and as little as 1mm or less minimum. The recesses may, in some cases, be on the order of between a tenth of a millimeter and half a millimeter deep, while the radial gap passages, spoke passages, and the branch passages may be on the order of two to ten millimeters in width in some implementations.

[0082] It will also be appreciated that the junctions between branch passages or between branch passages and spoke passages may also be rounded (despite being shown as having sharp corners in the figures).

[0083] Showerhead such as those discussed herein offer very low flow volumes due to replacing some large internal plenums with the various branch and radial spoke passages; this makes such showerheads particularly well-suited for providing rapid

transient response times, which may enable such showerheads to reach steady state flow conditions in a much shorter interval compared to showerheads with larger internal flow volumes. The use of the concentric rings of annular sub-plenums that are supplied by the low-volume branch and radial spoke passages may also provide more uniform gas flow from the center of the showerhead to the outer edge.

[0084] The showerheads discussed above may be mounted in a semiconductor processing chamber, e.g., as shown schematically in FIG. 16. As seen in FIG. 16, a showerhead 110 may be mounted to a chamber 102 (or positioned within the chamber 102, depending on the specific configuration) such that it is positioned over a wafer support or pedestal 104 that may support a wafer 106 during wafer processing operations. Various other equipment may be included as well, e.g., valve manifolds that may be controlled to provide different gases at different times to the showerhead via the gas inlet 118, radio frequency (RF) power sources that may be used to provide RF power to the chamber 102, heaters, cooling systems, etc.

[0085] FIG. 17 is a schematic of a processing system suitable for conducting semiconductor processing operations using a showerhead or showerheads as described above. The system 1700 includes a transfer module 1703 that may provide a clean, pressure-controlled environment to minimize risk of contamination of substrates being processed as they are moved between various reactor modules. Mounted on the transfer module 1703 is a multi-station reactor or processing chamber 1709 capable of performing various semiconductor processing operations according to various embodiments. The multi-station chamber 1709 may include multiple stations 1711, 1713, 1715, and 1717 that a wafer may be transferred between in order to sequentially perform various processing operations on the wafer. Such stations may include a pedestal or substrate support, as well as a showerhead, such as one of the showerheads discussed above.

[0086] Mounted on the transfer module 1703 may be one or more single or multi-station modules 1707 capable of performing plasma or chemical (non-plasma) pre-cleans, other deposition operations, or etch operations. The module may also be used for various treatments to, for example, prepare a substrate for a deposition process. The system 1700 also includes one or more wafer source modules 1701, where wafers may be stored before and after processing. An atmospheric robot (not shown) in atmospheric

transfer chamber 1719 may first remove wafers from the wafer source modules 1701 to loadlocks 1721 before the wafers are transferred into the transfer module 1703. A wafer transfer device (generally a robot arm unit) in the transfer module 1703 may move the wafers from loadlocks 1721 to and between the modules mounted on the transfer module 1703.

[0087] The processing system may also include a controller, e.g., controller 1742, that may be connected with various elements of the semiconductor processing tool and which may be configured to control various operational parameters of such a tool.

[0088] It will be appreciated that the example semiconductor processing tools discussed above may be equipped or connected with one or more such controllers that may be configured to control various functionalities associated with such semiconductor processing tools, for example, the raising and lowering of lift pins and/or the movement of robot arms and/or the actuation of slit valves and/or the timing and duration of gas delivery to the chamber, for example. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, such as processes for providing gas flows to a wafer via a showerhead, moving payloads between a process chamber and another chamber, loading/unloading wafers onto adapter rings, transporting payloads and/or wafers between one chamber and another, performing measurements on wafers placed in a metrology station, detecting one or more characteristics of a wafer using one or more sensors, etc.

[0089] Broadly speaking, the controller 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 in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some examples, be part of a recipe defined by process engineers to

accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0090] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g. a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus, as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

[0091] Without limitation, example tools according to the present disclosure may include semiconductor processing tools with a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition

(CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

5 **[0092]** As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and
10 from tool locations and/or load ports in a semiconductor manufacturing factory.

[0093] The use, if any, of ordinal indicators, e.g., (a), (b), (c)... or (1), (2), (3)... or the like, in this disclosure and claims is to be understood as not conveying any particular order or sequence, except to the extent that such an order or sequence is explicitly indicated. For example, if there are three steps labeled (i), (ii), and (iii), it is to be
15 understood that these steps may be performed in any order (or even concurrently, if not otherwise contraindicated) unless indicated otherwise. For example, if step (ii) involves the handling of an element that is created in step (i), then step (ii) may be viewed as happening at some point after step (i). Similarly, if step (i) involves the handling of an element that is created in step (ii), the reverse is to be understood. It is
20 also to be understood that use of the ordinal indicator “first” herein, e.g., “a first item,” should not be read as suggesting, implicitly or inherently, that there is necessarily a “second” instance, e.g., “a second item.”

[0094] It is to be understood that the phrases “for each <item> of the one or more <items>,” “each <item> of the one or more <items>,” or the like, if used herein, are
25 inclusive of both a single-item group and multiple-item groups, i.e., the phrase “for ... each” is used in the sense that it is used in programming languages to refer to each item of whatever population of items is referenced. For example, if the population of items referenced is a single item, then “each” would refer to only that single item (despite the fact that dictionary definitions of “each” frequently define the term to refer to “every
30 one of two or more things”) and would not imply that there must be at least two of those items. Similarly, the term “set” or “subset” should not be viewed, in itself, as necessarily encompassing a plurality of items—it will be understood that a set or a

subset can encompass only one member or multiple members (unless the context indicates otherwise).

[0095] 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.

[0096] The term “operatively connected” is to be understood to refer to a state in which two components and/or systems are connected, either directly or indirectly, such that, for example, at least one component or system can control the other. For example, a controller may be described as being operatively connected with a resistive heating unit, which is inclusive of the controller being connected with a sub-controller of the resistive heating unit that is electrically connected with a relay that is configured to controllably connect or disconnect the resistive heating unit with a power source that is capable of providing an amount of power that is able to power the resistive heating unit so as to generate a desired degree of heating. The controller itself likely cannot supply such power directly to the resistive heating unit due to the currents involved, but it will be understood that the controller is nonetheless operatively connected with the resistive heating unit.

[0097] 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. In the context of the first and second passage segments discussed in this application, however, it will be understood that when reference is made to such a passage segment fluidically connecting with other passage segments, such fluidic connections are to be understood to be direct couplings between such passage segments, e.g., the end of such a passage segment is directly connected to the ends of the other passage segments (as opposed to being connected with such other passage segments via one or more other intervening passage segments). 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
5 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
10 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.

[0098] It is understood that the examples and implementations described herein are
15 for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art. Although various details have been omitted for clarity's sake, various design alternatives may be implemented. Therefore, the present examples are to be considered as illustrative and not restrictive, and the disclosure is not to be limited to the details given herein but may be modified within
20 the scope of the disclosure.

[0099] It is to be understood that the above disclosure, while focusing on a particular example implementation or implementations, is not limited to only the discussed example, but may also apply to similar variants and mechanisms as well, and such similar variants and mechanisms are also considered to be within the scope of this
25 disclosure.

CLAIMS

What is claimed is:

1. An apparatus comprising:

a showerhead comprising:

5 a first side having a plurality of gas distribution ports;

a second side facing in an opposite direction from the first side of the showerhead and having a gas inlet;

a gas distribution plenum; and

10 a plurality of flow networks, each flow network comprising a corresponding spoke passage, a pair of corresponding first branch passages, a quartet of corresponding second branch passages, and a plurality of corresponding riser passages, wherein:

the gas distribution ports extend from the first side of the showerhead to the gas distribution plenum,

15 the corresponding spoke passage, corresponding first branch passages, and corresponding second branch passages of each flow network each includes a respective inlet end and a respective outlet end,

the respective inlet end of the corresponding spoke passage of each flow network is connected to the gas inlet,

20 the respective outlet end of the corresponding spoke passage of each flow network is connected to the respective inlet ends of the corresponding first branch passages of that flow network,

25 the respective outlet end of each of the corresponding first branch passages of each flow network is connected to the respective inlet ends of two of the corresponding second branch passages of that flow network,

each corresponding riser passage of each flow network is connected to the gas distribution plenum,

30 the corresponding riser passages of each flow network comprise a first set of corresponding riser passages for that flow network and a second set of corresponding riser passages for that flow network, and

the corresponding riser passages in the first set of corresponding riser passages for each flow network are each positioned closer to a center of the gas inlet than the corresponding riser passages in the second set of corresponding riser passages for that flow network.

2. The apparatus of claim 1, wherein:

the plurality of flow networks comprises a first set of flow networks and a second set of flow networks,

5 the corresponding riser passages in the first set of corresponding riser passages for each flow network in the first set of flow networks are each positioned at a first distance from a center of the gas inlet,

the corresponding riser passages in the second set of corresponding riser passages for each flow network in the first set of flow networks are each positioned at a second distance from a center of the gas inlet,

10 the corresponding riser passages in the first set of corresponding riser passages for each flow network in the second set of flow networks are each positioned at a third distance from a center of the gas inlet,

15 the corresponding riser passages in the second set of corresponding riser passages for each flow network in the second set of flow networks are each positioned at a fourth distance from a center of the gas inlet,

the first distance is smaller than the second distance,

the second distance is smaller than the third distance, and

the third distance is smaller than the fourth distance.

20 3. The apparatus of claim 2, wherein:

the flow networks in the second set of flow networks each further comprise an octet of corresponding third branch passages,

the corresponding third branch passages of each flow network in the second set of flow networks each includes a respective inlet end and a respective outlet end, and

25 the respective outlet end of each of the corresponding second branch passages of each flow network in the second set of flow networks is connected to the respective inlet ends of two of the corresponding third branch passages of that flow network.

4. The apparatus of claim 3, wherein:

30 each flow network in the first set of flow networks has four riser passages in the plurality of corresponding riser passages for that flow network,

each outlet end of each second branch passage of each flow network in the first set of flow networks is connected to a different one of the four riser passages for that flow network,

each flow network in the second set of flow networks has eight riser passages in the plurality of corresponding riser passages for that flow network, and

each outlet end of each third branch passage of each flow network in the second set of flow networks is connected to a different one of the eight riser passages for that flow network.

5

5. The apparatus of claim 4, wherein:

each corresponding second branch passage of each flow network in the first set of flow networks extends along a corresponding first axis that passes through the gas inlet, and

10 each corresponding second branch passage of each flow network in the second set of flow networks extends along a corresponding second axis that passes through the gas inlet.

6. The apparatus of claim 5, wherein each corresponding first axis is coaxial with a different one of the corresponding second axes.

15 7. The apparatus of any of claims 3 through 6, wherein the corresponding spoke passages of the flow networks in the first set of flow networks have larger respective minimum cross-sectional areas than the corresponding spoke passages of the flow networks in the second set of flow networks.

20 8. The apparatus of any of claims 1 through 7, wherein the corresponding spoke passages of at least some of the flow networks are linear and extend along corresponding axes extending radially outward from the gas inlet.

25 9. The apparatus of any of claims 1 through 8, wherein the corresponding second branch passages of at least some of the flow networks are linear and extend along corresponding axes that pass through the gas inlet.

10. The apparatus of any of claims 1 through 9, wherein the corresponding first branch passages of at least some of the flow networks follow arcuate paths.

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11. The apparatus of claim 3 and optionally including the elements of any of claims 4 through 10, wherein the corresponding third branch passages of at least some of the flow networks follow arcuate paths.

12. The apparatus of any of claims 1 through 11, further comprising a plurality of baffle wall segments, wherein:

5 the baffle wall segments are arranged in multiple concentric circular patterns within the gas distribution plenum and spaced apart from circumferentially adjoining baffle wall segments by corresponding radial gap passages.

13. The apparatus of claim 12, wherein at least some of the corresponding riser passages connect with the gas distribution plenum at respective corresponding ones of the corresponding radial gap passages.

10

14. The apparatus of claim 13, wherein:

the baffle wall segments extend between a first side of the gas distribution plenum and a second side of the gas distribution plenum,

the gas distribution plenum is subdivided into multiple annular sub-plenums,

15 each annular sub-plenum is bounded by the baffle wall segments in radially adjacent ones of the concentric circular patterns of baffle wall segments, and

each annular sub-plenum has a corresponding plenum thickness defined by a distance between the first side of the gas distribution plenum and the second side of the gas distribution plenum within that annular sub-plenum.

20

15. The apparatus of claim 14, wherein the corresponding plenum thicknesses of at least some of the annular sub-plenums are different.

16. The apparatus of claim 14 or claim 15, wherein at least some of the radial gap passages
25 include recesses in one or both of the first side of the gas distribution plenum and the second side of the gas distribution plenum.

17. The apparatus of claim 16, wherein the recesses of at least some of the radial gap passages with associated recesses extend into only one of the annular sub-plenums adjacent to
30 the corresponding radial gap passages associated with those recesses.

18. The apparatus of claim 16 or claim 17, wherein the recesses of at least some of the radial gap passages including recesses extend into both of the annular sub-plenums adjacent to the corresponding radial gap passages associated with those recesses.

19. The apparatus of any of claims 1 through 18, wherein the corresponding first branch passages in the first set of flow networks are all the same length.

5 20. The apparatus of any of claims 1 through 19, wherein the corresponding second branch passages in the first set of flow networks are all the same length.

21. The apparatus of claim 3 and optionally including the elements of any of claims 4 through 20, wherein the corresponding third branch passages in the first set of flow networks are all the same length.

10

22. The apparatus of any of claims 1 through 21, wherein the corresponding first branch passages and the corresponding second branch passages of each flow network are arranged in a configuration having an "H" shape.

15 23. The apparatus of claim 3 and optionally including the elements of any of claims 4 through 21, wherein:

the corresponding first branch passages and the corresponding second branch passages of each flow network are arranged in a configuration having an "H" shape, and

20 each corresponding second branch passage of each flow network in the second set of flow networks and the corresponding third branch passages connected to that corresponding second branch passage are also arranged in a configuration having an "H" shape.