DUAL PLENUM SHOWERHEAD

CLAIM OF PRIORITY

[0001] This application claims the benefit of priority to U.S. Patent Application Serial No. 63/547,660, filed on November 7, 2023, and titled "DUAL PLENUM SHOWERHEAD," which application is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The subject matter disclosed herein generally relates to systems, methods, apparatuses, and machine-readable media associated with a dual plenum showerhead in semiconductor substrate processing systems.

BACKGROUND

[0003] Semiconductor substrate processing systems are used to process semiconductor substrates by techniques including etching, physical vapor deposition (PVD), chemical vapor deposition (CVD), plasma-enhanced chemical vapor deposition (PECVD), atomic layer deposition (ALD), plasma-enhanced atomic layer deposition (PEALD), pulsed deposition layer (PDL), plasma-enhanced pulsed deposition layer (PEPDL) processing, and resist removal.

[0004] Some semiconductor substrate processing systems use process gases (or precursors) that are highly reactive. Exposing such reactive precursors to each other can cause supply line clogging and film defects during substrate manufacturing.

[0005] The background description provided herein is to present the context of the disclosure. It should be noted that the information described in this section is given to provide the skilled artisan with some context for the following disclosed subject matter and should not be considered as admitted prior art. More specifically, the work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not

precursor into the process chamber via the first delivery passageway and the first plenum. The control signal further causes the delivery of the second precursor into the process chamber via the second delivery passageway and the second plenum.

[0009] In yet another example embodiment, a method for processing a substrate using a dual plenum showerhead includes receiving a first process gas into a first plenum of a dual plenum showerhead via a first delivery passageway. The method further includes receiving a second process gas into a second plenum of the dual plenum showerhead via a second delivery passageway. The method further includes diffusing the first process gas and the second process gas into the first plenum and the second plenum, respectively. The method further includes delivering the first process gas and the second process gas into a process chamber of a semiconductor substrate processing apparatus via the first delivery passageway and the second delivery passageway, respectively. The method further includes controlling one or more parameters associated with the receiving, the diffusing, and the delivering of the first process gas and the second process gas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Various appended drawings illustrate examples of the present disclosure and cannot be considered limiting of its scope.

[0011] **FIG. 1** is a functional block diagram of an example of a substrate processing system in which examples of the present disclosure may be used.

[0012] **FIG. 2** illustrates a cross-sectional view of an example single plenum showerhead.

[0013] **FIG. 3A** illustrates a bottom-side view of a dual plenum showerhead, according to some example embodiments.

[0014] **FIG. 3B** illustrates a perspective cross-sectional view of the dual plenum showerhead of **FIG. 3A**, according to some example embodiments.

[0015] **FIG. 3C** illustrates perspective views of the face plate and the back plate of the dual plenum showerhead of **FIG. 3A** and **FIG. 3B,** including cross-drilled channels forming a first plenum, according to some example embodiments.

[0016] **FIG. 3D** illustrates a perspective view of a dual plenum showerhead section and a bottom-side view of an outer surface of the dual plenum showerhead of **FIG. 3A** and **FIG. 3B**, according to some example embodiments.

[0017] **FIG. 3E** illustrates another view of the dual plenum showerhead section of **FIG. 3D**, according to some example embodiments.

[0018] **FIG. 3F** illustrates a perspective view of a dual plenum band of the dual plenum showerhead of **FIG. 3A** and **FIG. 3B**, according to some example embodiments.

[0019] **FIG. 3G** illustrates a cross-sectional view of the dual plenum band of **FIG. 3F**, according to some example embodiments.

[0020] **FIG. 3H** illustrates a cross-sectional view of the dual plenum showerhead of **FIG. 3A**, according to some example embodiments.

[0021] **FIG. 3I** illustrates a cross-sectional view of a dual plenum showerhead, according to some example embodiments.

[0022] **FIG. 3J** illustrates a cross-sectional view of a section of the dual plenum showerhead of **FIG. 3I**, according to some example embodiments.

[0023] **FIG. 3K** illustrates a cross-sectional perspective view of a section of the dual plenum showerhead of **FIG. 3I**, according to some example embodiments.

[0024] **FIG. 3L** illustrates a bottom-side view of the dual plenum showerhead of **FIG. 3I**, according to some example embodiments.

[0025] **FIG. 4A** and **FIG. 4B** illustrate cross-sectional views of the dual plenum showerhead of **FIG. 3A** and **FIG. 3B**, according to example embodiments.

[0026] **FIG. 5** illustrates a perspective cross-sectional view of a showerhead adjuster, which can be used with the dual plenum showerhead of **FIG. 3A** and **FIG. 3B**, according to example embodiments.

gases within a process chamber (e.g., an ALD process chamber). A CVD processing system can operate without plasma, while a plasma-enhanced CVD (or PE-CVD) processing system is configured to operate with plasma. Similarly, an ALD processing system can be configured to operate with or without plasma. The process gases (e.g., precursor gases) are used to form (e.g., during multiple ALD cycles) a thin film deposition of a material on a substrate, such as a silicon wafer, as used in the semiconductor industry. The precursor gases can be sequentially introduced into the ALD processing chamber from a gas source so that the gases react with the surface of the substrate to form a deposition layer upon combining. For example, the substrate is typically exposed to process gases, including a first chemical (or a combination of chemicals) to form an absorbed layer. The excess of the first chemical or chemicals can be removed by pumping or purging. The process gases can include at least a second chemical or a combination of chemicals. The at least a second chemical can be introduced to react with the absorbed layer to form a deposited material layer. The two chemicals or combinations of chemicals can be selected specifically to react with one another to form the deposited material layer. However, such mutually reactive process gases can cause supply line clogging and film defects. The disclosed dual plenum showerhead can be used to prevent drawbacks associated with using mutually reactive precursors.

[0032] In some aspects, substrate processing systems can be used for nanolaminate film processes, including alternating deposition of layers (e.g., alternating deposition between AlO and SiO layers). In some aspects, two of the four precursors used in such processes are highly reactive and cannot be delivered in the same supply gas line path before entering the reaction chamber. In some aspects, the disclosed dual plenum showerhead can configure two separate gas/precursor delivery paths.

[0033] Current deposition process modules can deposit AlO or SiO films independently, either in a single-station module (SSM) or quad-station module (QSM) configuration. This limitation has reduced wafer throughput and increased process development cycle time.

[0034] The disclosed dual plenum showerhead can prevent precursors from interacting with each other before entering the reaction chamber, thus enabling nanolaminate film development under one process module reaction chamber. The disclosed dual plenum showerhead is configured with separate gas delivery passageways and separate plenums for delivering the process gases into the reaction (or process) chamber. In some aspects, the two separate gas delivery passageways are configured to be concentric in relation to each other (e.g., both passages have a common central axis, which can be the central axis of the showerhead stem).

[0035] A more detailed description of the dual plenum showerhead is provided in connection with **FIG. 1**. **FIGS. 3A-5** illustrate different configurations and views of the dual plenum showerhead configured according to the disclosed techniques. **FIG. 6** is a flowchart of a method for processing a substrate using a dual plenum showerhead.

[0036] **FIG. 1** is a functional block diagram of an example of a substrate processing system 100 in which examples of the present disclosure may be used. Referring now to **FIG. 1**, the example substrate processing system 100 is configured for performing deposition as shown. While a PECVD substrate processing system is shown as substrate processing system 100, a PEALD substrate processing system or other substrate processing system (e.g., a processing system without using plasma for deposition or etching) may be used in connection with the cleaning techniques discussed herein. The substrate processing system 100 includes a process chamber 102 that encloses other components of the substrate processing system 100 and contains plasma. The process chamber 102 includes a gas distribution device 104 and substrate support 106, such as an electrostatic chuck (ESC). During operation, substrate 108 is arranged on the substrate support 106. In some embodiments, the substrate support can include one or more pedestals.

[0037] In some examples, the gas distribution device 104 may include a showerhead 109 that distributes process gases over substrate 108 and serves as an electrode to apply an RF field that induces ion bombardment. The showerhead 109 may include a stem portion (e.g., stem 162), including one end connected to

the top surface of the process chamber 102. A base portion (e.g., base 164) is generally cylindrical and extends radially outwardly from an opposite end of the stem portion at a location that can be spaced from the top surface of the process chamber 102. In some aspects, base 164 includes one or more gas feed plates (e.g., a gas feed lower plate and a gas feed upper plate). A substrate-facing surface of the gas feed lower plate (also referred to as a faceplate) of the base 164 of the showerhead 109 includes a plurality of distributed holes through which process gas (or gases) flows. The gas distribution device 104 may be made of a metallic material and may act as an upper electrode. Alternatively, the gas distribution device 104 may be made of a non-metallic material and may include an embedded electrode. In other examples, the upper electrode may include a conducting plate, and the process gases may be introduced in another manner.

[0038] The substrate support 106 includes a conductive baseplate 110 that acts as a lower electrode. The baseplate 110 supports a heating plate 112, which may correspond to a ceramic multi-zone heating plate. A thermal resistance layer 114 may be arranged between the heating plate 112 and the baseplate 110. Baseplate 110 may include one or more coolant channels 116 for flowing coolant through the baseplate 110.

[0039] A Radio Frequency (RF) generating system 120 generates and outputs an RF voltage to one of the upper electrodes (e.g., the gas distribution device 104) and the lower electrode (e.g., the baseplate 110 of the substrate support 106). The other one of the upper electrode and the lower electrode may be direct current (DC) grounded at ground terminal 143, alternating current (AC) grounded, or floating. In some examples, the RF generating system 120 may supply dual-frequency power, including a high frequency (HF) generator 121 and a low frequency (LF) generator 122 that generate the HF and LF power (at predetermined frequencies and power levels, respectively) that is fed by a matching and distribution network 124 to the upper electrode or the lower electrode (or the showerhead).

[0040] A chemical delivery system 130 (also referred to as a chemical delivery module, a precursor delivery module, or a gas delivery module) includes process gas sources (such as one or more precursor canisters) 132-1, …, 132-N

(collectively, process gas sources 132), where N is an integer greater than one. The process gas sources are fluidly coupled (e.g., via a plurality of gas lines) to corresponding valves 134-1, …, 134-N (collectively, valves 134). Even though **FIG. 1** illustrates process gas sources as supplying nitrogen (N_2) and helium (He); other gases can be used as well.

[0041] The process gas sources 132 supply one or more process gas mixtures, dopants, carrier gases, liquid precursors, precursor gases, cleaning gases, and/or purge gases. In some examples, the chemical delivery system 130 delivers a precursor gas, such as a mixture of tetraethyl orthosilicate (TEOS) gas, a gas including an oxygen species and argon (Ar) gas during deposition, and dopants including triethyl phosphate (TEPO) and/or triethyl borate (TEB). In some examples, diffusion of the dopants occurs from the gas phase. For example, a carrier gas (e.g., nitrogen, argon, or other) is enriched with the desired dopant (also in gaseous form, e.g., TEPO and/or TEB) and supplied to the silicon wafer on which a concentration balance can take place. In subsequent processes, a wafer may be placed in a quartz tube that is heated to a specific temperature.

[0042] Returning to **FIG. 1**, the process gas sources 132 are connected by valves 134-1, …, 134-N and mass flow controllers (MFCs) 136-1, …, 136-N (collectively, MFCs 136) to a mixing manifold 140. The process gases are supplied to the mixing manifold 140 and mixed therein. The mixing manifold 140 is in fluid communication with valves 178-2 and valves 178-3 via supply line 183, which valves are fluidly coupled to showerhead 109 via supply line 182. More specifically, the outputs of valves 178-2 and valves 178-3 are fed to process chamber 102 via supply line 182, connecting mixing manifold 140 with the first inlet 166 at the stem 162 of showerhead 109. In some aspects, manifold 140 and manifold 180 are heated to a predetermined temperature to supply the precursor gases to the process chamber at a specific temperature (or a temperature range).

[0043] In some applications, there may be one or more valves between the mixing manifold 140 and the first inlet 166. In some embodiments, the substrate processing system 100 includes advanced modular precursor delivery systems (AMPDSs) 173-1, 173-2, 173-3, and 173-4 configured to supply precursor gases (also referred to as precursors or process gases) to process chamber 102 via the

first inlet 166 or a second inlet 168 at the stem 162 of showerhead 109. AMPDS 173-1 includes MFC 174-1, ampoule 176-1, and valve 178-1. AMPDS 173-2 includes MFC 174-2, ampoule 176-2, and valve 178-2. AMPDS 173-3 includes MFC 174-3, ampoule 176-3, and valve 178-3. AMPDS 173-4 includes MFC 174-4, ampoule 176-4, and valve 178-4. Ampoules 176-1 – 176-4 are configured to contain precursors, which can be of hazardous process material type (HPM-type) and/or non-HPM type.

[0044] Even though **FIG. 1** illustrates each of the AMPDSs 173-1, 173-2, 173-3, and 173-4 as including an MFC, an ampoule, and valves, the disclosure is not limited in this regard, and other components can be included as well in each AMPDS (e.g., level sensors, pneumatic valve banks, heaters, manometers, valve sensors, pressure gauge monitors, controllers, etc.).

[0045] MFCs 174-1 – 174-4 receive push gas (or carrier gas) via supply line 170 coupled to the output of at least one of valves 134 (e.g., valve 134-N). In some aspects, the push/carrier gas from supply line 170 is supplied to manifold 172, which distributes the push/carrier gas to an output of one or more of the ampoules 176-1 – 176-4 (e.g., ampoule 176-1 as illustrated in **FIG. 1**). In some aspects, the push/carrier gas from supply line 170 is also supplied to manifold 180, which distributes the push/carrier gas to an output of ampoule 176-4 and/or to the process chamber 102.

[0046] In some aspects, ampoule 176-2 supplies a non-HPM type precursor to the first inlet 166 of showerhead 109 via supply line 182, and ampoule 176-4 supplies an HPM-type precursor to the second inlet 168 of showerhead 109 via supply line 184. Even though **FIG. 1** illustrates the substrate processing system 100 as including four AMPDSs, the disclosure is not limited in this regard, and a different number (e.g., less than four or more than four) can be used instead. Additionally, each of the AMPDSs can be configured with a different type of precursor (HPM or non-HPM-based precursor in accordance with the substrate processing recipe).

[0047] In some embodiments, the substrate processing system 100 comprises a remote plasma source 152 configured to generate plasma and radicals from cleaning gas and purge gas. In some aspects, remote plasma source 152 is

supplied by process gas sources 132 or other process gas sources. An MFC 156 is coupled upstream from the remote plasma source 152. The cleaning gas and the purge gas can be supplied to showerhead 109 (e.g., via the first inlet 166) for performing in-situ cleaning of process chamber 102. More specifically, the cleaning gas and the purge gas are supplied to showerhead 109 via supply line 158, valve 154, and stem 162 of showerhead 109. In some embodiments, valve 154 and/or MFC 156 may not be present. In some aspects, the remote plasma source 152 can be part of the chemical delivery system 130.

[0048] A temperature controller 142 may be connected to a plurality of thermal control elements (TCEs) 144 arranged in the heating plate 112. For example, the plurality of TCEs 144 may include, but are not limited to, respective macro TCEs corresponding to each zone in a multi-zone heating plate and/or an array of micro TCEs disposed across multiple zones of a multi-zone heating plate. The temperature controller 142 may be used to control the plurality of TCEs 144 to control the temperature of the substrate support 106 and the substrate 108. Even though **FIG. 1** illustrates the TCEs in the substrate support structure, the disclosure is not limited in this regard, and the TCEs can be configured in other areas of the chamber (e.g., the chamber walls). Such TCEs configured in the chamber walls could control the chamber wall temperature, which could suppress deposition and assist with the chamber cleaning techniques discussed herein (e.g., by increasing the reactivity of clean gases arriving at wall surfaces).

[0049] The temperature controller 142 may communicate with a coolant assembly 146 to control coolant flow through channels 116. For example, the coolant assembly 146 may include a coolant pump and reservoir. The temperature controller 142 operates the coolant assembly 146 to selectively flow the coolant through channels 116 to cool the substrate support 106. A valve 148 (e.g., a gate valve) and a pump 150 (e.g., an exhaust pump) may be used to control pressure and to evacuate reactants from the process chamber 102. In an example embodiment, the process chamber may include more than one gate valve (or other types of valves) for evacuating reactants (e.g., process gases or cleaning gases) and purging gases from the chamber.

[0050] A system controller 160 may be used to control components of the substrate processing system 100. For example, the system controller 160 can be configured to control the supply of cleaning gas, purging gas, or precursors via the first inlet 166 or the second inlet 168 of the showerhead 109. The system controller 160 can be configured to perform other control functionalities, such as dynamically monitoring and adjusting the surface temperature of the heating elements of gas lines within the chemical delivery system 130. The system controller 160 can also be configured to perform pressure control functions, such as monitoring and adjusting the pressure within the process chamber 102. Although shown as separate controllers, the temperature controller 142 may be implemented within the system controller 160.

[0051] In some aspects, the system controller 160 can perform control functionalities associated with each of the AMPDSs 173-1, 173-2, 173-3, and 173-4. In some aspects, AMPDSs 173-1, 173-2, 173-3, and 173-4 can each include a controller, which is monitored (e.g., configured or controlled) by the system controller 160. Additionally, the system controller 160 can control the flow of process gases through the first inlet 166 and the second inlet 168 of the dual plenum showerhead 109.

[0052] **FIG. 2** illustrates a cross-sectional view of an example single plenum showerhead 200. The showerhead 200 includes a stem 202 with a single passageway and a single plenum 204. To introduce different process gases using showerhead 200, long purge times may be required to switch from one gas to another. Additionally, mutually reactive precursors can cause clogging of gas lines and film defects when used with the single plenum showerhead 200. These drawbacks can be avoided by using the dual plenum showerhead discussed in connection with **FIGS. 3A-6**.

[0053] **FIG. 3A** illustrates a bottom-side view 300A of a dual plenum showerhead 302, according to example embodiments. Referring to **FIG. 3A**, the bottom-side view 300A shows an outer surface 311 of the face plate 303 of the dual plenum showerhead 302. The outer surface 311 includes holes 352 (also referred to as distributed holes). A perspective cross-sectional view 300B of the dual plenum showerhead 302 along sectional line 301 is illustrated in **FIG. 3B**.

inches to approximately about 0.31 inches. In some embodiments, the distance between at least two neighboring holes of the second set of holes 356 is from approximately about 0.29 inches to approximately about 0.31 inches. In some embodiments, the distance between a first hole from the first set of holes 354 and a neighboring second hole from the second set of holes 356 is from approximately about 0.205 inches to approximately about 0.219 inches. As explained below, the distances between neighboring holes can be selected to configure a specific flow rate of the dual plenum showerhead.

[0064] **FIG. 3C** illustrates perspective views 300C and 302C of the face plate and the back plate of the dual plenum showerhead of **FIG. 3A** and **FIG. 3B,** including cross-drilled channels forming a first plenum, according to some example embodiments.

[0065] In some aspects, channels 313 include a plurality of cross-drilled channels 326 (illustrated in view 300C) and a plurality of cross-drilled channels 328 (illustrated in view 302C). More specifically, the plurality of cross-drilled channels 326 and the plurality of cross-drilled channels 328 are cross-drilled in the face plate 303 to form the first plenum 309. In some aspects, the plurality of cross-drilled channels 326 and the plurality of cross-drilled channels 328 are cross-drilled to be orthogonal to each other (e.g., as illustrated in **FIG. 3C**).

[0066] In some aspects, the plurality of cross-drilled channels 326 includes approximately about 35-45 channels cross-drilled in a first direction, and the plurality of cross-drilled channels 328 includes approximately about 35-45 channels cross-drilled in a second direction that is orthogonal to the first direction.

[0067] In some aspects, the diameter of each channel of the plurality of cross-drilled channels 326 and the plurality of cross-drilled channels 328 is selected from the range of approximately about 0.155 inches to approximately about 0.275 inches.

[0068] In some aspects, the diameter of holes 352 (including the first set of holes 354 and the second set of holes 356 shown in **FIG. 3B**) is selected from the range of approximately about 0.020 inches to approximately about 0.040 inches.

[0073] In some embodiments, holes 330, 331, 332, and 333 can be considered a third set of holes that is part of (e.g., a subset of) the second set of holes 356, and hole 334 can be considered part of the first set of holes 354. In some aspects, a distance between at least two neighboring holes of the third set of holes (e.g., distance 358 between holes 330 and 333 or distance 360 between holes 333 and 331) is from approximately about 0.29 inches to approximately about 0.31 inches. It is advantageous to have holes 330, 331, 332, and 333 form a square pattern around the center region of the showerhead (e.g., around hole 334, which can be configured as the center hole of spigot 325), where all the sides have the same length. Spigot 325 can be configured to maintain a specific cavity size within the showerhead at the center location. By arranging the holes 330, 331, 332, and 333 in a square pattern, underneath the spigot 325, gas from the second plenum 307 will be able to mix more uniformly around the center region with gas from the first plenum 309.

[0074] In some embodiments, a distance between at least two non-neighboring holes of the third set of holes (e.g., distance 362 between holes 330 and 331) is from approximately about 0.410 inches to approximately about 0.438 inches.

[0075] In some aspects, the angle (e.g., drill angle) associated with channels 335, 336, 338, and 339 can vary from approximately about 23 degrees to approximately about 60 degrees (e.g., as illustrated in **FIG. 3E**). In some aspects, the non-orthogonal angle associated with channels 335, 336, 338, and 339 is determined based on the diameter of channels 313 so that a uniform arrangement of holes 330, 331, 332, 333, and 334 is achieved (e.g., as illustrated in bottom-side view 302D). In some aspects, the distance between each two neighboring holes of holes 352 (e.g., between each two neighboring holes of holes 330, 331, 332, 333, and 334) can be maintained the same (e.g., at approximately about 0.200 inches to approximately about 0.250 inches). In some aspects, the distance is about 0.210 inches.

[0076] It is advantageous to have each of holes 330, 331, 332, and 333 (i.e., holes connected to slanted channels such as channels 335, 336, 338, and 339) be arranged at an equal distance to hole 334 (i.e., vertical center hole connected to

FIG. 3H, cross-sectional view 300H is similar to the perspective cross-sectional view 300B of the dual plenum showerhead 302 in **FIG. 3B**. Cross-sectional view 300H illustrates sections 364 and 366 of the face plate 303. More specifically, section 364 illustrates a cross-sectional view showing channels 313 and corresponding outlet channels of the first set of outlet channels 321. As seen in **FIG. 3H**, section 364 illustrates outlet channel 340 and corresponding hole 334 associated with channel 372 centered at a vertical axis of spigot 325.

[0085] Section 366 illustrates a cross-sectional view of an edge portion of the face plate 303. More specifically, section 366 illustrates channel 368 as the outer channel of the channels 313 within the first plenum 309. Additionally, section 366 illustrates a void portion 370 of the first plenum 309, with the void portion 370 disposed between channel 368 and the dual plenum band 342. In some aspects, the void portion 370 does not include any of the channels 313 or outlet channels of the first set of outlet channels 321.

[0086] **FIG. 3I** illustrates a cross-sectional view 300I of a dual plenum showerhead, according to some example embodiments. Referring to **FIG. 3I**, cross-sectional view 300I illustrates the dual plenum showerhead 302 configured according to another embodiment (e.g., as illustrated by sections 364 and 366 in **FIG. 3I**). More specifically, section 364 illustrates that channel 372 is configured without outlet channel 340 and the corresponding hole 334. Additionally, section 366 illustrates that the dual plenum showerhead 302 of **FIG. 3I** includes a void portion 370 that is configured to include one or more additional outlet channels (e.g., outlet channels 374 and 376) as part of the first set of outlet channels 321.

[0087] **FIG. 3J** illustrates a cross-sectional view 300J of a section of the dual plenum showerhead of **FIG. 3I**, according to some example embodiments. Referring to **FIG. 3J**, cross-sectional view 300J is a more detailed view of section 364 of the dual plenum showerhead embodiment of **FIG. 3I**. More specifically, cross-sectional view 300J illustrates that the area 378 adjacent to (e.g., below) channel 372 is configured not to include outlet channel 340 and the corresponding hole 334.

[0088] **FIG. 3K** illustrates a cross-sectional perspective view 300K of a section of the dual plenum showerhead of **FIG. 3I**, according to some example

further includes the second set of outlet channels 319 that fluidly couple the second plenum 307 to the outer surface 311 of the face plate 303 via the second set of holes 356.

[0093] In some aspects, the illustrated parts/components of the dual plenum showerhead 302 are sealed (e.g., with O-rings or other sealing techniques) so that no atmospheric penetration into the first plenum 309 and the second plenum 307 is possible.

[0094] **FIG. 5** illustrates a perspective cross-sectional view 500 of a showerhead adjuster, which can be used with the dual plenum showerhead of **FIG. 3A**, according to example embodiments. Referring to **FIG. 5**, cross-sectional view 500 illustrates a portion of a dual plenum showerhead, including a first stem portion 502 (with a first inlet 514 and a first delivery passageway 504) and a second stem portion 503 (with a second inlet 508 and a second delivery passageway 506).

[0095] In some aspects, the portion of the dual plenum showerhead illustrated in cross-sectional view 500 further includes a showerhead adjuster 512 and a showerhead locking nut 510. In some aspects, showerhead adjuster 512 and showerhead locking nut 510 can be configured to adjust the following parameters associated with the dual plenum showerhead:

[0096] (a) Distance: The distance between the showerhead face plate and the pedestal underneath can be adjusted. This will determine the nominal gap between the showerhead and pedestal during substrate processing.

[0097] (b) Parallelism: the showerhead adjuster 512 can be configured with three jacking screws that control the showerhead faceplate plane with respect to the pedestal (this adjustment can determine the process uniformity on the wafer).

[0098] In some aspects, one or more components of the showerhead adjuster 512 can include at least one heater element to heat one or more of the process gases as they are delivered through the first stem portion 502 and the second stem portion 503.

[0099] **FIG. 6** is a flowchart of method 600 for processing a substrate in a process chamber using a dual plenum showerhead, according to an example

and a static memory 706, some or all of which may communicate with each other via an interlink 708 (e.g., a bus). The machine 700 may further include a display device 710, an alphanumeric input device 712 (e.g., a keyboard), and a user interface (UI) navigation device 714 (e.g., a mouse). In an example, the display device 710, alphanumeric input device 712, and UI navigation device 714 may be a touch screen display. Machine 700 may additionally include a mass storage device (e.g., drive unit) 716, a signal generation device 718 (e.g., a speaker), a network interface device 720, and one or more sensors 721. Machine 700 may include an output controller 728, such as a serial (e.g., universal serial bus (USB)), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC)) connection to communicate with or control one or more peripheral devices (e.g., a printer, card reader).

[0108] In an example embodiment, the hardware processor 702 may perform the functionalities of the system controller 160 to configure and control functionalities described herein in connection with configuring a dual-plenum showerhead.

[0109] The mass storage device 716 may include a machine-readable medium 722 on which one or more sets of data structures or instructions 724 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein can be stored. Instructions 724 may also reside, completely or at least partially, within the main memory 704, within the static memory 706, or the hardware processor 702 during execution thereof by machine 700. In some aspects, one or any combination of the hardware processor 702, the main memory 704, the static memory 706, or the mass storage device 716 may constitute machine-readable media.

[0110] While the machine-readable medium 722 is illustrated as a single medium, the term "machine-readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database and/or associated caches and servers) configured to store the one or more instructions 724.

[0111] The term "machine-readable medium" may include any medium that is capable of storing, encoding, or carrying instructions 724 for execution by machine 700 and that causes machine 700 to perform any one or more of the

need not be physically located together but may comprise disparate instructions stored in separate locations, which, when joined logically together, comprise the component or module and achieve the stated purpose for the component or module.

[0114] Indeed, a component or module of executable code may be a single instruction or many instructions and may even be distributed over several different code segments, among different programs, and across several memory devices or processing systems. In particular, some aspects of the described process (such as code rewriting and code analysis) may take place on a different processing system (e.g., in a computer in a data center) than that in which the code is deployed (e.g., in a computer embedded in a sensor or robot). Similarly, operational data may be identified and illustrated herein within components or modules and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set or may be distributed over separate locations, including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. The components or modules may be passive or active, including agents operable to perform desired functions.

[0115] Given the above-described implementations of subject matter, this application discloses the following list of examples, wherein one feature of an example in isolation or more than one feature of an example, taken in combination and, optionally, in combination with one or more features of one or more further examples, are further examples also falling within the disclosure of this application.

[0116] Example 1 is a dual plenum showerhead assembly, comprising a stem comprising a first delivery passageway and a second delivery passageway; a back plate coupled to the stem; and a face plate coupled to the back plate, the face plate and the back plate defining a first plenum and a second plenum therebetween, the first plenum configured to receive a first process gas exclusively via the first delivery passageway, the second plenum configured to receive a second process gas exclusively via the second delivery passageway, and the first delivery

passageway and the second delivery passageway being orthogonal to an outer surface of the face plate.

[0117] In Example 2, the subject matter of Example 1 includes subject matter where the stem comprises a first stem portion including the first delivery passageway, the first stem portion comprising a top side with a first inlet and a bottom side coupled to the back plate, the first inlet to receive the first process gas.

[0118] In Example 3, the subject matter of Example 2 includes subject matter where the stem comprises a second stem portion including a second inlet, the second inlet to receive the second process gas.

[0119] In Example 4, the subject matter of Example 3 includes subject matter where the second stem portion is configured to receive the first stem portion within a cavity of the second stem portion.

[0120] In Example 5, the subject matter of Example 4 includes subject matter where the second delivery passageway is formed between an inner surface of the second stem portion and the outer surface of the first stem portion, and wherein the second delivery passageway includes the second inlet.

[0121] In Example 6, the subject matter of Examples 1–5 includes subject matter where the first plenum is disposed between the face plate and the second plenum, and wherein the second plenum is disposed between the first plenum and the back plate.

[0122] In Example 7, the subject matter of Example 6 includes subject matter where the first plenum further comprises a first set of outlet channels that fluidly couple the first plenum to the outer surface of the face plate.

[0123] In Example 8, the subject matter of Example 7 includes subject matter where the first set of outlet channels fluidly couples the first plenum to the outer surface of the face plate via a first set of holes.

[0124] In Example 9, the subject matter of Examples 7–8 includes subject matter where the second plenum further comprises a second set of outlet channels that fluidly couple the second plenum to the outer surface of the face plate via a second set of holes, wherein the second set of outlet channels comprises at least a third set of outlet channels (e.g., a subset of the second set of outlet channels) that

is fluidly coupled to the second plenum, and each outlet channel of the third set of outlet channels is non-orthogonal in relation to the outer surface of the face plate.

[0125] In Example 10, the subject matter of Example 9 includes subject matter where the third set of outlet channels is associated with a third set of holes, and where a distance between at least two neighboring holes of the third set of holes is from approximately about 0.29 inches to approximately about 0.31 inches.

[0126] In Example 11, the subject matter of Example 10 includes subject matter where a distance between at least two non-neighboring holes of the third set of holes is from approximately about 0.410 inches to approximately about 0.438 inches.

[0127] In Example 12, the subject matter of Examples 1–11 includes subject matter where the second delivery passageway is concentric in relation to the first delivery passageway.

[0128] Example 13 is a semiconductor substrate processing apparatus, the semiconductor substrate processing apparatus comprising: a showerhead comprising: a stem comprising a first delivery passageway and a second delivery passageway; a back plate coupled to the stem; and a face plate coupled to the back plate, the face plate and the back plate defining a first plenum associated with the first delivery passageway and a second plenum associated with the second delivery passageway, and the first delivery passageway and the second delivery passageway being orthogonal to an outer surface of the face plate; a chemical delivery system, the chemical delivery system comprising: a first precursor delivery apparatus configured to store a first precursor; and a second precursor delivery apparatus configured to store a second precursor; a process chamber in which a semiconductor substrate is processed, the process chamber fluidly coupled to the showerhead; and a controller configured to generate a control signal associated with processing the semiconductor substrate, the control signal causing delivery of the first precursor into the process chamber via the first delivery passageway and the first plenum, and the control signal further causing delivery of the second precursor into the process chamber via the second delivery passageway and the second plenum.

[0129] In Example 14, the subject matter of Example 13 includes subject matter where the second delivery passageway is concentric in relation to the first delivery passageway.

[0130] In Example 15, the subject matter of Example 14 includes subject matter where the stem comprises a first stem portion including the first delivery passageway, the first stem portion comprising a top side with a first inlet and a bottom side coupled to the back plate, the first inlet to receive the first precursor.

[0131] In Example 16, the subject matter of Example 15 includes subject matter where the stem comprises a second stem portion including a second inlet, the second inlet to receive the second precursor.

[0132] In Example 17, the subject matter of Example 16 includes subject matter where the second stem portion is configured to receive the first stem portion within a cavity of the second stem portion.

[0133] In Example 18, the subject matter of Example 17 includes subject matter where the second delivery passageway is formed between an inner surface of the second stem portion and the outer surface of the first stem portion, and wherein the second delivery passageway includes the second inlet.

[0134] In Example 19, the subject matter of Examples 13–18 includes subject matter where the first plenum is disposed between the face plate and the second plenum, and wherein the second plenum is disposed between the first plenum and the back plate.

[0135] In Example 20, the subject matter of Example 19 includes subject matter where the first plenum further comprises a first set of outlet channels that fluidly couple the first plenum to the outer surface of the face plate via a first set of holes.

[0136] In Example 21, the subject matter of Example 20 includes subject matter where the second plenum further comprises a second set of outlet channels that fluidly couple the second plenum to the outer surface of the face plate via a second set of holes.

[0137] Example 22 is a method for processing a substrate using a dual plenum showerhead, the method comprising receiving a first process gas into a

first plenum of the dual plenum showerhead via a first delivery passageway; receiving a second process gas into a second plenum of the dual plenum showerhead via a second delivery passageway; diffusing the first process gas and the second process gas into the first plenum and the second plenum, respectively; delivering the first process gas and the second process gas into a process chamber of a semiconductor substrate processing apparatus via the first delivery passageway and the second delivery passageway, respectively; and controlling one or more parameters associated with the receiving, the diffusing, and the delivering of the first process gas and the second process gas.

[0138] In Example 23, the subject matter of Example 22 includes receiving the first process gas via a first inlet, the first inlet configured in a first stem portion of a stem of the dual plenum showerhead.

[0139] In Example 24, the subject matter of Example 23 includes receiving the second process gas via a second inlet, the second inlet configured in a second stem portion of the stem, wherein the first stem portion is disposed within the second stem portion of the stem to form the second delivery passageway.

[0140] Example 25 is at least one machine-readable medium including instructions that, when executed by processing circuitry, cause the processing circuitry to perform operations to implement any of Examples 1–24.

[0141] Example 26 is an apparatus comprising means to implement any of Examples 1–24.

[0142] Example 27 is a system to implement any of Examples 1–24.

[0143] Example 28 is a method to implement any of Examples 1–24.

[0144] Throughout this specification, plural instances may implement components, operations, or structures described as a single instance. Although individual operations of one or more methods are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated. Structures and functionality that are presented as separate components, for example, configurations, may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single

component may be implemented as separate components. These and other variations, modifications, additions, and improvements fall within the scope of the subject matter herein.

[0145] The embodiments illustrated herein are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed. Other embodiments may be used and derived from there, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. The Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[0146] The claims may not set forth every feature disclosed herein, as embodiments may feature a subset of said features. Further, embodiments may include fewer features than those disclosed in a particular example. Thus, the following claims are now incorporated into the Detailed Description, with a claim standing on its own as a separate embodiment.

[0147] As used herein, the term "or" may be construed in either an inclusive or exclusive sense. Moreover, plural instances may be provided for resources, operations, or structures described herein as a single instance. Additionally, boundaries between various resources, operations, modules, engines, and data stores are arbitrary, and particular operations are illustrated in the context of specific illustrative configurations. Other allocations of functionality are envisioned and may fall within the scope of various embodiments of the present disclosure. In general, structures and functionality presented as separate resources in the example configurations may be implemented as a combined structure or resource. Similarly, structures and functionality presented as a single resource may be implemented as separate resources. These and other variations, modifications, additions, and improvements fall within the scope of embodiments of the present disclosure as represented by the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

1. A dual plenum showerhead assembly, comprising:

a stem comprising a first delivery passageway and a second delivery passageway;

a back plate coupled to the stem; and

a face plate coupled to the back plate, the face plate and the back plate defining a first plenum and a second plenum therebetween, the first plenum configured to receive a first process gas exclusively via the first delivery passageway, the second plenum configured to receive a second process gas exclusively via the second delivery passageway, and the first delivery passageway and the second delivery passageway being orthogonal to an outer surface of the face plate.

2. The dual plenum showerhead assembly of claim 1, wherein the stem comprises:

a first stem portion including the first delivery passageway, the first stem portion comprising a top side with a first inlet and a bottom side coupled to the back plate, the first inlet to receive the first process gas.

3. The dual plenum showerhead assembly of claim 2, wherein the stem comprises:

a second stem portion including a second inlet, the second inlet to receive the second process gas.

4. The dual plenum showerhead assembly of claim 3, wherein the second stem portion is configured to receive the first stem portion within a cavity of the second stem portion.

5. The dual plenum showerhead assembly of claim 4, wherein the second delivery passageway is formed between an inner surface of the second stem portion and the outer surface of the first stem portion, and wherein the second delivery passageway includes the second inlet.

6. The dual plenum showerhead assembly of claim 1, wherein the first plenum is disposed between the face plate and the second plenum, and wherein the second plenum is disposed between the first plenum and the back plate.

7. The dual plenum showerhead assembly of claim 6, wherein the first plenum further comprises a first set of outlet channels that fluidly couple the first plenum to the outer surface of the face plate, and wherein at least one of the first set of outlet channels is disposed in a volume of the first plenum that is proximate to a dual plenum band of the dual plenum showerhead assembly.

8. The dual plenum showerhead assembly of claim 7, wherein the first set of outlet channels fluidly couples the first plenum to the outer surface of the face plate via a first set of holes.

9. The dual plenum showerhead assembly of claim 7, wherein the second plenum further comprises a second set of outlet channels that fluidly couple the second plenum to the outer surface of the face plate via a second set of holes, wherein the second set of outlet channels comprises at least a third set of outlet channels that is fluidly coupled to the second plenum, and each outlet channel of the third set of outlet channels is non-orthogonal in relation to the outer surface of the face plate.

10. The dual plenum showerhead assembly of claim 9, wherein the third set of outlet channels is associated with a third set of holes, the third set of holes being part of the second set of holes, and wherein a distance between at least two neighboring holes of the third set of holes is from approximately about 0.29 inches to approximately about 0.31 inches.

11. The dual plenum showerhead assembly of claim 10, wherein a distance between at least two non-neighboring holes of the third set of holes is from approximately about 0.410 inches to approximately about 0.438 inches.

12. The dual plenum showerhead assembly of claim 1, wherein the second delivery passageway is concentric in relation to the first delivery passageway.

13. A semiconductor substrate processing apparatus, the semiconductor substrate processing apparatus comprising:

a showerhead comprising:

a stem comprising a first delivery passageway and a second delivery passageway;

a back plate coupled to the stem; and

a face plate coupled to the back plate, the face plate and the back plate defining a first plenum associated with the first delivery passageway and a second plenum associated with the second delivery passageway, and the first delivery passageway and the second delivery passageway being orthogonal to an outer surface of the face plate;

a chemical delivery system, the chemical delivery system comprising:

a first precursor delivery apparatus configured to store a first precursor; and

a second precursor delivery apparatus configured to store a second precursor;

a process chamber in which a semiconductor substrate is processed, the process chamber fluidly coupled to the showerhead; and

a controller configured to generate a control signal associated with processing the semiconductor substrate, the control signal causing delivery of the first precursor into the process chamber via the first delivery passageway and the first plenum, and the control signal further causing delivery of the second precursor into the process chamber via the second delivery passageway and the second plenum.

14. The semiconductor substrate processing apparatus of claim 13, wherein the second delivery passageway is concentric in relation to the first delivery passageway.

15. The semiconductor substrate processing apparatus of claim 14, wherein the stem comprises:

a first stem portion including the first delivery passageway, the first stem portion comprising a top side with a first inlet and a bottom side coupled to the back plate, the first inlet to receive the first precursor.

16. The semiconductor substrate processing apparatus of claim 15, wherein the stem comprises:

a second stem portion including a second inlet, the second inlet to receive the second precursor.

17. The semiconductor substrate processing apparatus of claim 16, wherein the second stem portion is configured to receive the first stem portion within a cavity of the second stem portion, wherein the second delivery passageway is formed between an inner surface of the second stem portion and the outer surface of the first stem portion, and wherein the second delivery passageway includes the second inlet.

19. A method for processing a substrate using a dual plenum showerhead, the method comprising:

receiving a first process gas into a first plenum of the dual plenum showerhead via a first delivery passageway;

receiving a second process gas into a second plenum of the dual plenum showerhead via a second delivery passageway;

diffusing the first process gas and the second process gas into the first plenum and the second plenum respectively;

delivering the first process gas and the second process gas into a process chamber of a semiconductor substrate processing apparatus via the first delivery passageway and the second delivery passageway respectively; and

controlling one or more parameters associated with the receiving, the diffusing, and the delivering of the first process gas and the second process gas.

20. The method of claim 19, further comprising:

receiving the first process gas via a first inlet, the first inlet configured in a first stem portion of a stem of the dual plenum showerhead; and

receiving the second process gas via a second inlet, the second inlet configured in a second stem portion of the stem, wherein the first stem portion is disposed within the second stem portion of the stem to form the second delivery passageway.