[0015] **FIG. 5A** and **FIG. 5B** illustrate perspective views of an AMPDS showing a common frame and a plurality of interchangeable side panels, according to example embodiments.

[0016] **FIG. 6** illustrates a perspective view of a disassembled AMPDS, such as the AMPDS of **FIG. 3**, according to example embodiments.

[0017] **FIG. 7A**, **FIG. 7B**, **FIG. 7C**, and **FIG. 7D** illustrate different views of an AMPDS side panel with gasketing, according to example embodiments.

[0018] **FIG. 8A** is an example AMPDS for a non-HPM type precursor, according to example embodiments.

[0019] **FIG. 8B** is an example AMPDS for an HPM type precursor, according to example embodiments.

[0020] **FIG. 9A** and **FIG. 9B** illustrate example configurable openings of a side panel for an HPM AMPDS, according to example embodiments.

[0021] **FIG. 9C** and **FIG. 9D** illustrate example configurable openings of a side panel for a non-HPM AMPDS, according to example embodiments.

[0022] **FIG. 10** is a flowchart of a method for processing a substrate in a process chamber with multiple AMPDSs, according to an example embodiment.

[0023] **FIG. 11** is a block diagram illustrating an example of a machine upon which one or more example method embodiments may be implemented or by which one or more example embodiments may be controlled.

DETAILED DESCRIPTION

[0024] The description that follows includes systems, methods, techniques, instruction sequences, and computing machine program products (e.g., stored on machine-readable media) that embody illustrative embodiments of the present disclosure. In the following description, for purposes of explanation, numerous specific details are outlined to provide a thorough understanding of example embodiments directed to reconfigurable advanced modular precursor delivery systems (AMPDSs) used in semiconductor substrate processing systems.

It will be evident, however, to one skilled in the art that the present embodiments may be practiced without these specific details.

[0025] In this application, the terms "semiconductor wafer," "wafer," "substrate," "semiconductor substrate," and "wafer substrate" are used interchangeably. The terms "chamber," "reaction chamber," "deposition chamber," "reactor," "chemical isolation chamber," "process chamber," "processing chamber," and "substrate processing chamber" are also used interchangeably.

[0026] One type of a substrate processing system (also referred to as a substrate processing apparatus) can include a process chamber containing top and bottom electrodes where radio frequency (RF) power is applied between the electrodes to excite a process gas into a plasma for processing semiconductor substrates in the process chamber. Another type of substrate processing apparatus can include an ALD tool, which is a specialized type of CVD processing system in which ALD reactions occur between two or more chemical species introduced as process gasses within a process chamber (e.g., an ALD process chamber). A CVD processing system can be configured to 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 gasses (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 gasses, 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 gasses 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 explicitly selected to react with one another to form the deposited material layer.

[0027] Existing deposition process modules utilize a full-size AMPDS enclosure design, which occupies valuable space on the module. In some aspects, the AMPDS configuration can include two precursors or three precursors. The disclosed techniques can be used to implement a compact hardware design such that the process module's upper frame area can adapt at least three AMPDS and an extra AMPDS in the lower frame area.

[0028] The disclosed AMPDS configurations include using a single common frame (or skeleton) as the baseline for the AMPDSs used in a substrate processing apparatus (also referred to as a process module). Additionally, the AMPDS can be configured with a plurality of interchangeable side panels, with specific hardware mounting selected for optional features. In this regard, both non-HPM and HPM precursors can be configured with the disclosed AMPDS hardware design using the same (common) frame. In some aspects, automated precursor bulk-fill capability can be enabled with ampoule liquid level sensors and software control (e.g., using EtherCAT-based communications). By using a common frame and a plurality of interchangeable side panels that are configurable (e.g., with louver openings or other mounting options to mount additional components on the panels), the disclosed AMPDS is modular, allowing for compact implementation and ease of configuration and re-configuration based on the desired precursor and associated modules or components used in connection with delivery of such precursor to the process chamber via a showerhead.

[0029] A more detailed description of a substrate processing apparatus (or a process module) with a process chamber and multiple AMPDSs is provided in connection with **FIG. 1**. **FIGS. 2-9D** illustrate different configurations of AMPDSs configured according to disclosed techniques. **FIG. 10** is a flowchart of a method for processing a substrate using a process module with multiple AMPDSs.

[0030] **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 precursor delivery 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.

[0031] 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. Alternately, 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.

[0032] 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.

[0033] 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).

[0034] 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. Even though **FIG. 1** illustrates process gas sources as supplying nitrogen (N_2) and helium (He); other gases can be used as well.

[0035] The process gas sources 132 supply one or more process gas mixtures, dopants, carrier gases, liquid precursors, precursor gases, cleaning gases, and 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 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 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.

[0036] Returning to **FIG. 1**, the process gas sources 132 are connected by valves 134-1, …, 134-N (collectively, valves 134) 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).

[0037] 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 AMPDSs 173-1, 173-2, 173-3, and 173-4 configured to supply precursor gases (or precursors) 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 HPM-type and non-HPM type.

[0038] 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.). In some aspects, AMPDSs 173-1, 173-2, 173-3, and 173-4 can be configured with the same frame, but the interchangeable side panels for the openings of the frame can be selected so that a particular set of components can be fit inside the frame cavity as well as mounted on one or more of the side panels (e.g., based on a precursor type contained by each AMPDS). The disclosed modularity design of the AMPDSs allows flexibility for different precursor configurations with different numbers of channels (CHs) being used on the same process module (e.g., 2-CH, 3-CH, or 4-

CH versions on the same tool). Example configurations of such AMPDSs associated with a modular design (e.g., using the same frame with interchangeable and individually configurable side panels) are discussed in connection with **FIGS. 2-11**.

[0039] 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 the process chamber 102.

[0040] 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). In some aspects, AMPDSs 173-1, 173-2, 173-3, and 173-4 are configured according to the disclosed configurations discussed concerning **FIGS. 2-11**.

[0041] 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 processing 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 MFC 156 may not be present. In some aspects, the remote plasma source 152 can be part of the chemical delivery system 130.

[0042] 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 TCEs 144 may include, but are not limited to, respective macro TCEs corresponding to each zone in a multi-zone heating plate and 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 chamber cleaning during operation of the substrate processing system 100 (e.g., by increasing the reactivity of cleaning gases arriving at wall surfaces).

[0043] 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 processing 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.

[0044] 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 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.

[0045] 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.

[0046] **FIG. 2** illustrates a perspective view of a substrate processing system using multiple AMPDSs, according to example embodiments. Referring to **FIG. 2**, the substrate processing system 200 includes a gas delivery section 202, a showerhead section 204 (e.g., with one or more showerheads), a deposition chamber section 206 (e.g., with one or more process chambers), and a gas box 208. In some aspects, gas box 208 includes a chemical delivery system (e.g., chemical delivery system 130 of **FIG. 1**).

[0047] In some embodiments, the gas delivery section houses multiple AMPDSs, such as AMPDS 210A (which can be the same as AMPDS 173-1 of **FIG. 1**), AMPDS 210B (which can be the same as AMPDS 173-2 of **FIG. 1**), and AMPDS 210D (which can be the same as AMPDS 173-4 of **FIG. 1**). In some aspects, AMPDS 210C (which can be the same as AMPDS 173-3 of **FIG. 1**) can be configured on an opposite side of the gas delivery section 202 (e.g., near the gas box 208, as illustrated in **FIG. 2**). Other configurations and a different number of AMPDSs is also possible within the substrate processing system 200.

[0048] **FIG. 3** illustrates a perspective view of an example AMPDS 300, according to example embodiments. Referring to **FIG. 3**, AMPDS 300 can be an AMPDS configured with an HPM-type precursor. In some aspects, AMPDS 300 includes a frame 302, interchangeable side panels (or side covers) (e.g., front side panel 306, top side panel 304, and left side panel 308, which are visible in **FIG. 3**), and additional components (or features) mounted on (or associated with) one or more of the side panels (e.g., components or features based on the type of precursor stored and delivered by the AMPDS).

[0049] For example, AMPDS 300 includes a continuous level sensor controller 314 (e.g., for controlling a continuous level sensor performing continuous sensing of the precursor level), a discrete level sensor controller 316 (e.g., for controlling a discrete level sensor performing discrete sensing of the precursor level), and a pneumatic valve bank 318 (e.g., a poly-tubing bulkhead pass-through), all mounted on the top side panel 304.

[0050] In some aspects, AMPDS 300 further includes a controller 310 and a differential pressure sensor 312 (also referred to as a pressure gauge monitor) mounted on the left side panel 308.

[0051] In some aspects, one or more of the side panels can be configured with louver openings (e.g., opening 305 on the top side panel 304) for ventilation, as well as other features (e.g., handle 307 on the front side panel 306). Additional features and configurations of the disclosed AMPDSs are illustrated in **FIGS. 4A-9D** and are discussed herein below.

[0052] **FIG. 4A**, **FIG. 4B**, and **FIG. 4C** illustrate corresponding perspective views 400A, 400B, and 400C of a common frame (e.g., frame 302), which can be used in different AMPDSs of a substrate processing system, according to example embodiments. Referring to **FIGS. 4A-4C**, frame 302 is configured with a plurality of openings that can be covered by a corresponding plurality of interchangeable side panels (e.g., as illustrated in **FIGS. 5A-5B**). More specifically, frame 302 is configured with a front side opening 402, a right side opening 404, a left side opening 406, a left rear side opening 408, a rear side opening 410, a right rear side opening 412, and a top side opening 414.

[0053] In some aspects, frame 302 is configured with a drip tray 416, which includes a precursor output port 418, which is used for outputting the precursor downstream to the process chamber (e.g., via a supply line fluidly coupled to the output port). In some aspects, drip tray 416 can include one or more sensors (e.g., spill sensors), which are not illustrated in **FIGS. 4A-4C**.

[0054] **FIG. 5A** and **FIG. 5B** illustrate corresponding perspective views 500A and 500B of an AMPDS showing a common frame (e.g., frame 302) and a plurality of interchangeable side panels, according to example embodiments.

More specifically, frame 302 is configured with a front-side panel 502 (for the front side opening 402), a right-side panel 504 (for the right side opening 404), a left-side panel 506 (for the left side opening 406), a left rear side panel 508 (for the left rear side opening 408), a rear side panel 510 (for the rear side opening 410), a right rear side panel 512 (for the right rear side opening 412), and a top side panel 514 (for the top side opening 414). As seen in **FIGS. 5A-5B**, side panels 502-514 can be configured with different openings or features (e.g., handles or half-shear features as illustrated in **FIGS. 7A-7D**).

[0055] **FIG. 6** illustrates a perspective view of a disassembled AMPDS, such as the AMPDS of **FIG. 3**, according to example embodiments. Referring to **FIG. 6**, AMPDS 600 can be an AMPDS configured with an HPM-type precursor. In some aspects, AMPDS 600 includes a frame 601, interchangeable side panels (or side covers) (e.g., front side panel 602, right side panel 604, left side panel 606, and top side panel 608 which are visible in **FIG. 6**), and additional components (or features) within the frame cavity or mounted on (or associated with) one or more of the side panels (e.g., components or features based on the type of precursor stored and delivered by the AMPDS).

[0056] For example, AMPDS 600 includes a continuous level sensor controller 614 (e.g., for controlling a continuous level sensor performing continuous sensing of the precursor level), a discrete level sensor controller 616 (e.g., for controlling a discrete level sensor performing discrete sensing of the precursor level), and a pneumatic valve bank 618 (e.g., a poly-tubing bulkhead pass-through) all mounted on the top side panel 608. The AMPDS 600 further includes a controller 610 and a differential pressure sensor 612 mounted on the left side panel 606. The AMPDS 600 further includes heaters 620, manometer 622, MFC 624, valve sensors 626, and other sensors (e.g., a continuous level sensor and a discrete level sensor not illustrated in **FIG. 6**).

[0057] In some aspects, the AMPDS controller (e.g., controller 610) is configured to control functionalities of the AMPDS components within the cavity of frame 601 and on the side panels that are removably attached to the cavity openings. For example, controller 610 controls functionalities of the continuous level sensor controller 614, the discrete level sensor controller 616, the pneumatic

valve bank 618, the differential pressure sensor 612, the heaters 620, the manometer 622, the MFC 624, and the valve sensors 626. In some embodiments, the controller 610, the manometer 622, and the MFC 624 are configured to communicate via an EtherCAT-based protocol.

[0058] **FIG. 7A**, **FIG. 7B**, **FIG. 7C**, and **FIG. 7D** illustrate different views of an AMPDS side panel with gasketing, according to example embodiments. In some embodiments, one or more of the side panels of an AMPDS can be configured with gasketing and a half-shear feature. More specifically, **FIG. 7A** illustrates a perspective view 709 of side panel 702, which is configured with gasketing 704 and a half-shear feature 706.

[0059] **FIG. 7B** illustrates a perspective view of section 708 from **FIG. 7A**, with the gasketing 704 unattached to the side panel 702. **FIG. 7C** illustrates a perspective view 710 of section 708 with the gasketing 704 attached to the side panel 702.

[0060] **FIG. 7D** illustrates a cross-sectional view 712 of the side panel 702 (with gasketing 704 attached to the panel) while the side panel is removably attached to the AMPDS frame 707. In some aspects, the half-shear feature 706 allows for the side panel 702 to be installed and torqued to standard values while maintaining optimal compression of the gasketing 704 for sealing.

[0061] **FIG. 8A** is an example side view of AMPDS 800A for a non-HPM type precursor with the front side panel removed, according to example embodiments. Referring to **FIG. 8A**, AMPDS 800A includes a frame 802A, interchangeable side panels (not referenced in **FIG. 8A**), a discrete level sensor controller 804A (e.g., for controlling discrete level sensor 810A that performs discrete sensing of the precursor level), a pneumatic valve bank 806A (e.g., a poly-tubing bulkhead pass-thorough), a controller 808A, MFC 812A, manometer 814A, valves 816A (with valve sensors), and heaters 818A. The heaters 818A are configured to wrap around, e.g., an evaporation canister (not referenced in **FIG. 8A**).

[0062] **FIG. 8B** is an example side view of AMPDS 800B for an HPM type precursor with the front side panel removed, according to

[0066] **FIG. 9C** and **FIG. 9D** illustrate perspective view 900C and front view 900D of example configurable openings of a side panel 912 for a non-HPM AMPDS, according to example embodiments. Referring to **FIGS. 9C-9D**, side panel 912, can be a rear side panel of a non-HPM AMPDS. In some aspects, side panel 912 is configured with openings based on the precursor type and to fit specific components of the AMPDS. In some aspects, side panel 912 includes a metal fitting passthrough opening 914, a heater alternating current (AC) connector opening 916, and a metal fitting bulkhead opening 918. In some aspects, a distinct set of openings can be configured for the side panel 912 of a non-HPM AMPDS.

[0067] **FIG. 10** is a flowchart of method 1000 for processing a substrate in a process chamber with multiple AMPDSs, according to an example embodiment. Method 1000 includes operations 1002, 1004, 1006, 1008, and 1010, which may be performed by control logic (or the control logic configures or causes other modules to perform the function), such as the system controller 160 and one or more of the controllers of AMPDSs 173-1 – 173-4 of **FIG. 1**. For example, the system controller 160 and one or more of the controllers of AMPDSs 173-1 – 173-4 can be configured to manage the operation of the substrate processing system 100, including configuration, activation, and deactivation of one or more of the AMPDSs 173-1 – 173-4 in connection with substrate processing.

[0068] At operation 1002, a chemical delivery system is configured. For example, referring to **FIG. 1**, the chemical delivery system includes a first precursor delivery apparatus (e.g., AMPDS 173-4) comprising a first frame and a second precursor delivery apparatus (e.g., AMPDS 173-2) comprising a second frame. The second frame can be the same as the first frame (e.g., as discussed in connection with **FIGS. 4A-5B**).

[0069] At operation 1004, the first precursor delivery apparatus (e.g., AMPDS 173-4) is configured with a hazardous process material (HPM) type precursor.

[0070] At operation 1006, the second precursor delivery apparatus (e.g., AMPDS 173-2) is configured with a non-HPM type precursor.

panels removably secured to the second frame to cover a corresponding opening of a plurality of openings of the second frame, and at least one of the second plurality of interchangeable side panels being configurable based on a precursor type associated with the second precursor.

[0103] In Example 20, the subject matter of Example 19 includes subject matter where the precursor type associated with the first precursor is a hazardous process material (HPM) type, and the precursor type associated with the second precursor is a non-HPM type.

[0104] In Example 21, the subject matter of Example 20 includes subject matter where the first precursor delivery apparatus comprises a differential pressure sensor mounted on at least one of the first plurality of interchangeable side panels, the differential pressure sensor configured to monitor the exhaust flow of the first precursor delivery apparatus.

[0105] In Example 22, the subject matter of Example 21 includes subject matter where the second precursor delivery apparatus comprises a discrete level sensor configured to sense a level of the precursor in discrete increments; and a discrete level sense controller configured to control operation of the discrete level sensor, wherein the discrete level sense controller is mounted on the at least one of the second plurality of interchangeable side panels.

[0106] In Example 23, the subject matter of Examples 21–22 includes subject matter where the at least one of the first plurality of interchangeable side panels and the at least one of the second plurality of interchangeable side panels each comprises gasketing and a half-shear feature, the half-shear feature configured to maintain compression of the gasketing when the respective interchangeable side panel is secured to the respective frame.

[0107] Example 24 is a method for processing a substrate in a process chamber, the method comprising configuring a chemical delivery system, the chemical delivery system comprising a first precursor delivery apparatus comprising a first frame and a second precursor delivery apparatus comprising a second frame, the second frame being same as the first frame; configuring the first precursor delivery apparatus with a hazardous process material (HPM) type precursor; configuring the second precursor delivery apparatus with a non-HPM type precursor; coupling the chemical delivery system to a showerhead of the process chamber; and generating one or more control signals to control delivery

of one or both of the HPM type precursor and the non-HPM type precursor to the process chamber via the showerhead.

[0108] In Example 25, the subject matter of Example 24 includes removably securing a first plurality of interchangeable side panels to the first frame of the first precursor delivery apparatus to cover a corresponding opening of a plurality of openings of the first frame.

[0109] In Example 26, the subject matter of Example 25 includes subject matter where at least one of the first plurality of interchangeable side panels is configurable based on the first precursor delivery apparatus storing the HPM-type precursor.

[0110] In Example 27, the subject matter of Example 26 includes monitoring the exhaust flow of the first precursor delivery apparatus using a differential pressure sensor, the differential pressure sensor mounted on the at least one of the first plurality of interchangeable side panels.

[0111] In Example 28, the subject matter of Examples 25–27 includes removably securing a second plurality of interchangeable side panels to the second frame of the second precursor delivery apparatus to cover a corresponding opening of a plurality of openings of the second frame.

[0112] In Example 29, the subject matter of Example 28 includes subject matter where at least one of the second plurality of interchangeable side panels is configurable based on the second precursor delivery apparatus storing the non-HPM type precursor.

[0113] In Example 30, the subject matter of Example 29 includes monitoring a level of the non-HPM precursor in discrete increments using a discrete level sensor, and controlling the monitoring using a discrete level sense controller, the discrete level sense controller mounted on the at least one of the second plurality of interchangeable side panels.

[0114] Example 31 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 1–30.

CLAIMS

1. A precursor delivery apparatus comprising:

a frame with a plurality of openings;

a container for storing a precursor, the container mounted within an internal volume formed by the frame; and

a plurality of interchangeable side panels, each of the plurality of interchangeable side panels removably secured to the frame to cover a corresponding opening of the plurality of openings, and at least one of the plurality of interchangeable side panels being configurable based on a precursor type associated with the precursor.

2. The precursor delivery apparatus of claim 1, further comprising:

a controller configured to generate a control signal to control release of the precursor to a gas showerhead of a process chamber via an output port associated with the container,

wherein the precursor type associated with the precursor is one of a hazardous process material (HPM) type and a non-HPM type.

3. The precursor delivery apparatus of claim 2, wherein the plurality of interchangeable side panels comprises a front side panel, a right side panel, a left side panel, a left rear side panel, a rear side panel, a right rear side panel, and a top side panel.

4. The precursor delivery apparatus of claim 3, wherein the left side panel comprises a configurable opening to accommodate the controller.

5. The precursor delivery apparatus of claim 4, wherein the precursor is of the HPM type and the precursor delivery apparatus further comprises:

a differential pressure sensor mounted on the left side panel, the differential pressure sensor configured to monitor exhaust flow of the precursor delivery apparatus.

6. The precursor delivery apparatus of claim 3, wherein the precursor is of the HPM type and the rear side panel comprises:

one or more metal fitting passthrough openings;

a heater alternating current (AC) connector opening; and

an enclosure exhaust outlet opening.

7. The precursor delivery apparatus of claim 6, further comprising:

a discrete level sensor configured to sense a level of the precursor in discrete increments; and

a continuous level sensor configured to perform continuous sensing of the level of the precursor.

8. The precursor delivery apparatus of claim 7, further comprising:

a discrete level sense controller configured to control operation of the discrete level sensor; and

a continuous level sense controller configured to control operation of the continuous level sensor.

9. The precursor delivery apparatus of claim 8, wherein the discrete level sense controller and the continuous level sense controller are mounted on the top side panel.

10. The precursor delivery apparatus of claim 4, wherein the precursor is of the non-HPM type and the rear side panel comprises:

a metal fitting passthrough opening;

a heater alternating current (AC) connector opening; and

a metal fitting bulkhead opening.

11. The precursor delivery apparatus of claim 10, further comprising:

a discrete level sensor configured to sense a level of the precursor in discrete increments.

12. The precursor delivery apparatus of claim 11, further comprising:

a discrete level sense controller configured to control operation of the discrete level sensor.

13. The precursor delivery apparatus of claim 12, wherein the discrete level sense controller is mounted on the top side panel.

14. The precursor delivery apparatus of any of claims 2-13, further comprising:

a manometer configured to measure at least a pressure of the precursor inside the container; and

a mass flow controller (MFC) configured to control flow of the precursor to the gas showerhead.

15. The precursor delivery apparatus of claim 14, wherein the control signal further controls the manometer and the MFC.

16. The precursor delivery apparatus of claim 15, wherein the controller, the manometer, and the MFC are configured to operate according to an EtherCAT-based protocol.

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

a showerhead;

a chemical delivery system, the chemical delivery system comprising:

a first precursor delivery apparatus comprising a first frame, the first precursor delivery apparatus configured to deliver a first precursor to the showerhead; and

a second precursor delivery apparatus comprising a second frame, the second precursor delivery apparatus configured to deliver a second precursor to the showerhead, and the second frame being same as the first frame;

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 causing a release of at least one of the first precursor and the second precursor into the showerhead during processing of the semiconductor substrate placed in the process chamber.

18. The semiconductor substrate processing apparatus of claim 17, wherein the first precursor delivery apparatus comprises:

a first plurality of interchangeable side panels, each of the first plurality of interchangeable side panels removably secured to the first frame to cover a corresponding opening of a plurality of openings of the first frame, and at least one of the first plurality of interchangeable side panels being configurable based on a precursor type associated with the first precursor.

19. The semiconductor substrate processing apparatus of claim 18, wherein the second precursor delivery apparatus comprises:

a second plurality of interchangeable side panels, each of the second plurality of interchangeable side panels removably secured to the second frame to cover a corresponding opening of a plurality of openings of the second frame, and at least one of the second plurality of interchangeable side panels being configurable based on a precursor type associated with the second precursor.

20. The semiconductor substrate processing apparatus of claim 19, wherein the precursor type associated with the first precursor is a hazardous process material (HPM) type, and the precursor type associated with the second precursor is a non-HPM type.

21. The semiconductor substrate processing apparatus of claim 20, wherein the first precursor delivery apparatus comprises a differential pressure sensor mounted on the at least one of the first plurality of interchangeable side panels, the differential pressure sensor configured to monitor exhaust flow of the first precursor delivery apparatus.

22. The semiconductor substrate processing apparatus of claim 21, wherein the second precursor delivery apparatus comprises:

a discrete level sensor configured to sense a level of the second precursor in discrete increments; and

a discrete level sense controller configured to control operation of the discrete level sensor,

wherein the discrete level sense controller is mounted on the at least one of the second plurality of interchangeable side panels.

23. The semiconductor substrate processing apparatus of claim 21, wherein the at least one of the first plurality of interchangeable side panels and the at least one of the second plurality of interchangeable side panels each comprises gasketing and a half-shear feature, the half-shear feature configured to maintain compression of the gasketing when the respective interchangeable side panel is secured to the respective frame.

24. A method for processing a substrate in a process chamber, the method comprising:

configuring a chemical delivery system, the chemical delivery system comprising a first precursor delivery apparatus comprising a first frame and a second precursor delivery apparatus comprising a second frame, the second frame being same as the first frame;

configuring the first precursor delivery apparatus with a hazardous process material (HPM)-type precursor;

configuring the second precursor delivery apparatus with a non-HPM type precursor;

coupling the chemical delivery system to a showerhead of the process chamber; and

generating one or more control signals to control delivery of one or both of the HPM-type precursor and the non-HPM-type precursor to the process chamber via the showerhead.

25. The method of claim 24, further comprising:

removably securing a first plurality of interchangeable side panels to the first frame of the first precursor delivery apparatus to cover a corresponding opening of a plurality of openings of the first frame.

26. The method of claim 25, wherein at least one of the first plurality of interchangeable side panels is configurable based on the first precursor delivery apparatus storing the HPM-type precursor.

27. The method of claim 26, further comprising:

monitoring exhaust flow of the first precursor delivery apparatus using a differential pressure sensor, the differential pressure sensor mounted on the at least one of the first plurality of interchangeable side panels.

28. The method of claim 25, further comprising:

removably securing a second plurality of interchangeable side panels to the second frame of the second precursor delivery apparatus to cover a corresponding opening of a plurality of openings of the second frame.

29. The method of claim 28, wherein at least one of the second plurality of interchangeable side panels is configurable based on the second precursor delivery apparatus storing the non-HPM type precursor.

30. The method of claim 29, further comprising:

monitoring a level of the non-HPM precursor in discrete increments using a discrete level sensor; and

controlling the monitoring using a discrete level sense controller, the discrete level sense controller mounted on the at least one of the second plurality of interchangeable side panels.