

MULTI-STATION PROCESSING TOOL WITH PRECURSOR DISTRIBUTION SYSTEM

BACKGROUND

[0001] Semiconductor device fabrication processes involves many steps of material deposition, patterning and removal to form integrated circuits on substrates. Various methods can be used to deposit films of materials onto a substrate. As an example, atomic layer deposition (ALD) forms a film using one or more deposition cycles. In a dose phase of an ALD cycle, a film precursor is adsorbed onto a surface of a substrate disposed in a processing chamber. Excess film precursor is purged from the processing chamber. Then, in a conversion phase of the ALD cycle, the adsorbed film precursor is chemically converted into a film on the substrate, for example, by oxidation. A highly conformal film of a target thickness can be grown using one or more ALD cycles.

SUMMARY

[0002] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

[0003] Examples are disclosed that relate to a dose-divert valve assembly for a precursor distribution system for a multi-station processing tool, and to multi-station processing tools with such dose-divert valve assemblies. One example provides a multi-

station processing tool that comprises two or more processing stations. The multi-station processing tool further comprises a precursor source. The multi-station processing tool further comprises a dose-divert valve assembly operable to selectively direct a precursor flow received from the precursor source between a dose path or a divert path. The dose-divert valve assembly includes a precursor inlet to receive the precursor flow from the precursor source. The dose-divert valve assembly further includes a dose valve operable to selectively provide the precursor flow to the dose path. The dose-divert valve assembly further includes a divert valve operable to selectively provide the precursor flow to the divert path. The multi-station processing tool further comprises a dose line comprising two or more branches. The dose line is connected to the dose valve. Each branch of the dose line fluidly couples the precursor source with a corresponding processing station of the two or more processing stations.

[0004] In some such examples, the dose-divert valve assembly is a first dose-divert valve assembly. The dose path comprises a dose manifold to which the first dose-divert valve assembly is coupled. The precursor source is a first precursor source. The multi-station processing tool further comprises a second precursor source and a second dose-divert valve assembly. The second precursor source is fluidly coupled with the second precursor source and with the dose manifold.

[0005] Additionally or alternatively, in some such examples, the dose manifold further includes a purge gas inlet to receive a purge gas from a purge gas source.

[0006] Additionally or alternatively, in some such examples, the divert path comprises a divert manifold to which the first dose-divert valve assembly and the second dose-divert valve assembly are fluidly coupled. The multi-station processing tool further comprises a divert line connected to the divert manifold.

[0007] Additionally or alternatively, in some such examples, the multi-station processing tool comprises four or more processing stations, and the dose line comprises four or more branches.

[0008] Additionally or alternatively, in some such examples, the two or more branches project radially outward from an upstream segment of the dose line.

[0009] Additionally or alternatively, in some such examples, the two or more processing stations are housed in a same processing chamber.

[0010] Additionally or alternatively, in some such examples, a first processing station of the two or more processing stations is housed in a first processing chamber, and a second processing station of the two or more processing stations is housed in a second processing chamber.

[0011] Additionally or alternatively, in some such examples, the multi-station processing tool further comprises a controller. The controller is configured to control an opening timing and a closing timing of the dose valve and to control an opening timing and a closing timing of the divert valve.

[0012] Another example provides a precursor distribution system for a multi-station processing tool. The system comprises a dose-divert valve assembly operable to selectively direct a precursor flow received from a precursor source between a dose path or a divert path. The dose-divert valve assembly includes a precursor inlet to receive the precursor flow from the precursor source. The dose-divert valve assembly further includes a dose valve operable to selectively provide the precursor flow to the dose path. The dose-divert valve assembly further includes a divert valve operable to selectively provide the precursor flow to the divert path. The system further comprises a dose line comprising two or more branches, the dose line configured to be connected to the dose valve. Each branch of the dose line is configured to be fluidly coupled with

a corresponding processing station of two or more processing stations of the multi-station processing tool.

[0013] In some such examples, the dose-divert valve assembly is a first dose-divert valve assembly and the precursor source is a first precursor source. The system further comprises a second dose-divert valve assembly operable to selectively direct a second precursor flow received from a second precursor source between a second dose path or a second divert path. The second dose-divert valve assembly includes a second precursor inlet to receive the second precursor flow from the second precursor source. The second dose-divert valve assembly further includes a second dose valve operable to selectively provide the second precursor flow from the second precursor source to the second dose path. The second dose-divert valve assembly further includes a second divert valve operable to selectively provide the second precursor flow from the second precursor source to the second divert path.

[0014] Additionally or alternatively, in some such examples, the dose path of the first dose-divert valve assembly and the second dose path of the second dose-divert valve assembly comprise a dose manifold to which the first dose-divert valve assembly and the second dose-divert valve assembly are fluidly coupled.

[0015] Additionally or alternatively, in some such examples, the dose manifold further includes a purge gas inlet to receive a purge gas from a purge gas source.

[0016] Additionally or alternatively, in some such examples, the system comprises a divert manifold to which the first dose-divert valve assembly and the second dose-divert valve assembly are fluidly coupled. The system further comprises a divert line configured to be connected to the divert manifold.

[0017] Additionally or alternatively, in some such examples, the divert path of the first dose-divert valve assembly and the second divert path of the second dose-divert valve assembly comprise the divert manifold.

[0018] Additionally or alternatively, in some such examples, the dose line comprises four or more branches for four or more processing stations.

[0019] Additionally or alternatively, in some such examples, the two or more branches are configured to project radially outward from an upstream segment of the dose line.

[0020] Additionally or alternatively, in some such examples, the dose valve and the divert valve are independently operable.

[0021] Another example provides a method operating a precursor delivery system for a multi-station processing tool. The method comprises controlling a dose valve of a dose-divert valve assembly to open for a target dose duration of time in advance of a dose phase of two or more processing stations to provide a precursor flow to a dose path. The method further comprises controlling the dose valve to close upon conclusion of the target dose duration. The method further comprises controlling a divert valve of the dose-divert valve assembly to open at a target divert timing in relation to the conclusion of the target dose duration to provide the precursor flow to a divert path.

[0022] In some such examples, the method further comprises, in advance of the dose valve being controlled to open, providing the precursor flow to the dose-divert valve assembly as a charge volume at a target pressure differential above a chamber pressure within one or more processing chambers housing the two or more processing stations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 schematically depicts an example of a multi-station processing tool for performing atomic layer deposition.

[0024] FIGS. 2A – 2H schematically depict example configurations of the multi-station processing tool of FIG. 1.

[0025] FIG. 3 schematically depicts an example configuration of a precursor distribution system of the multi-station processing tool of FIG. 1.

[0026] FIG. 4 depicts an example of a portion of the precursor distribution system according to the configuration of FIG. 4 in which various components are integrated with a manifold body.

[0027] FIG. 5 is a flow diagram depicting an example method of operating a dose-divert valve assembly in an ALD tool.

[0028] FIG. 6 schematically depicts an example computing system.

DETAILED DESCRIPTION

[0029] The term “assembly” generally represents a collection of two or more objects or components. The term “dose and divert valve assembly” generally represents an assembly that comprises a dose valve and a divert valve.

[0030] The term “atomic layer deposition” (ALD) generally represents a process in which a film is formed on a substrate in one or more individual layers by sequentially adsorbing a precursor conformally to the substrate and reacting the adsorbed precursor to form a film layer. Examples of ALD processes comprise plasma-enhanced ALD (PEALD) and thermal ALD (TALD). PEALD and TALD respectively utilize a plasma of a reactive gas and heat to facilitate a chemical conversion of a

precursor adsorbed to a substrate to a film on the substrate. The terms “growth” and “deposition”, and variants thereof, also can be used to refer to film formation.

[0031] The term “divert” generally represents the act or function of directing a material or object away from another path.

[0032] The term “divert valve” generally represents a represents a machine configured to selectively direct the flow of a fluid to a divert path.

[0033] The term “dose” generally represents exposing a substrate to a precursor for a duration.

[0034] The term “dose valve” generally represents a represents a machine configured to selectively direct a flow of a fluid to a dose path.

[0035] The term “fluid communication” generally represents a structural configuration that enables a fluid substance, such as a liquid or gas, to flow from one location to another.

[0036] The term “manifold” generally represents a machine or structure that connects or combines multiple inputs or outputs.

[0037] The term “plasma” generally represents a gas comprising cations and free electrons. A plasma can be used to generate reactive chemical species from a precursor molecule introduced into the plasma.

[0038] The term “plasma generator” generally represents hardware configured to form a plasma for processing a substrate in a processing chamber.

[0039] The term “precursor” generally represents a chemical compound that participates in a chemical reaction to produce a product compound.

[0040] The term “processing chamber” generally represents an enclosure in which chemical and/or physical processes are performed on substrates. The pressure,

temperature and atmospheric composition within a processing chamber are controllable to perform chemical and/or physical processes.

[0041] The term “processing station” generally represents a station within a substrate processing tool that performs one or more processing techniques on a substrate. A processing tool can have multiple processing stations in a processing chamber. A processing tool alternatively or additionally can have different multiple processing stations in different processing chambers.

[0042] The term “processing tool” generally represents a machine comprising a processing chamber and other hardware configured to perform substrate processing.

[0043] The terms “purge” and variants thereof represent processes in which species are removed from a processing chamber.

[0044] The term “showerhead” generally represents a processing chemical outlet comprising a plurality of holes distributed across an area.

[0045] The term “valve” generally represents a machine configured to control, regulate, and/or direct the flow of a fluid.

[0046] As briefly introduced above, atomic layer deposition (ALD) can be used to grow a film on a substrate in a layer by layer manner using one or more ALD cycles. Each ALD cycle forms one layer of a film. In an ALD cycle, a substrate in a processing chamber is first exposed to a precursor in a dose phase of an ALD cycle. The precursor adsorbs to the substrate in a self-limiting reaction. The processing chamber is then purged of excess precursor, and the adsorbed precursor is chemically converted to a film on the substrate in a conversion phase of the ALD process.

[0047] Precursor flow can be controlled at a processing station in an ALD tool by use of a dose valve and a divert valve. During a dose phase of an ALD cycle, the dose valve associated with the processing station is opened to deliver a precursor flow

to the substrate. When not in the dose phase, the dose valve is closed, and a divert valve is opened to divert the precursor flow to an exhaust system. This maintains a stable precursor flow that can be quickly provided to the processing station when needed.

[0048] In a multi-station processing tool, station-specific dose valves and divert valves can be used. The use of station-specific dose valves and divert valves allows the dose valves and divert valves to be located close to processing chemical inlets at respective processing stations. However, the use of a separate dose valve and divert valve for each processing station can be expensive. Further, each dose valve and divert valve requires separate maintenance.

[0049] Accordingly, examples are disclosed that relate to precursor distribution systems for multi-station processing tools in which a same dose valve and a same divert valve is used to control precursor flow to a plurality of processing stations. The term “dose-divert valve assembly” is used to represent an assembly that includes a dose valve and a divert valve. In one example, a precursor distribution system comprises a dose-divert valve assembly operable to selectively direct a precursor flow received from a precursor source between a dose path or a divert path. The dose-divert valve assembly includes a precursor inlet to receive a precursor from a precursor source. The dose-divert valve assembly further includes a dose valve operable to selectively provide the precursor flow to the dose path. The dose-divert valve assembly further includes a divert valve operable to selectively provide the precursor flow to the divert path. The precursor distribution system further comprises a dose line comprising two or more branches. The dose line is connected to the dose valve. Each branch of the dose line is fluidly coupled with a corresponding processing station.

[0050] The disclosed precursor distribution system provides a reduced number of valves compared to precursor distribution systems with station-specific dose and

divert valves. Further, the disclosed precursor distribution system can simplify precursor flow control hardware by allowing the omission of separate valves to control precursor flow from separate precursor sources into a common dose line.

[0051] Placement of dose-divert valve assemblies of the disclosed precursor distribution system upstream of station branches in the dose line can lead to increased delay between opening of the dose valve and delivery of the precursor to the processing stations compared to precursor distribution systems with station-specific dose valves and divert valves. This delay in precursor flow can be addressed by advancing an opening timing of the dose valve in relation to the dose phase. Alternatively or additionally, this delay in precursor flow can be addressed by increasing a pressure differential between the precursor flow and the chamber pressure within the processing chamber. Alternatively or additionally, this delay in precursor flow also can be addressed by reducing a cross-sectional area of the dose line compared to current precursor distribution systems for multi-station processing tools.

[0052] FIG. 1 schematically depicts an example of a multi-station tool 100 for performing atomic layer deposition. Processing tool 100 comprises one or more processing chambers. A first processing chamber 102-1 is depicted in FIG. 1. Processing chamber 102-1 comprises a first processing station 104-1. Processing station 104-1 comprises a pedestal 106 for supporting a substrate 108. Pedestal 106 includes a substrate heater 110 configured to heat substrate 108.

[0053] Processing station 104-1 further comprises a processing gas outlet 112. In the depicted example, the processing gas outlet 112 comprises a showerhead for directing a processing gas across an area of substrate 108. In other examples, processing station 104-1 alternatively or additionally can comprise a nozzle or other outlet structure.

[0054] In the example of FIG. 1, processing gas outlet 112 is fluidly connected to a remote plasma generator (RPG) 114. RPG 114 is configured to generate radical species from a gas-phase or vapor-based precursor. Alternatively or additionally, in some examples processing gas outlet 112 and/or pedestal 106 can be configured as electrodes for generating a capacitively coupled plasma for generating reactive species within processing chamber 102-1. Further, in some examples, RPG 114 can be omitted.

[0055] FIG. 1 schematically depicts additional processing stations of multi-station processing tool 100, including a second processing station 104-2 through an optional Nth processing station 104-N. The term “N” as used in various examples herein refers to an optional one or more instances beyond a last-numbered instance of a referred-to structure. Some or all of second processing station 104-2 through Nth processing station 104-N can be located within processing chamber 102-1 of processing tool 100, as described in further detail with reference to FIGS. 2A-2C. In some examples, some of second processing station 104-2 through Nth processing station 104-N can be located within one or more other processing chambers of processing tool 100, as described in further detail with reference to FIGS. 2D-2G. Each of processing station 104-2 through processing station 104-N can comprise a substrate holder, a substrate heater, a processing gas outlet, a plasma generator, and/or other hardware for processing a substrate.

[0056] Processing tool 100 further can comprise one or more precursor sources. Precursor sources can take various forms. In some examples, a precursor source can comprise a compressed gas. In other examples, a precursor source can comprise a condensed phase precursor that is vaporized for delivery to processing stations. FIG. 1 shows an example precursor source in the form of an ampoule 116 configured to hold a condensed phase precursor. Ampoule 116 comprises a flow-over vapor (FOV) gas

inlet 122 for flowing a carrier gas from a carrier gas source 124 into ampoule 116. FOV gas inlet 122 can include a mass flow controller for controlling the flow of the carrier gas. Ampoule 116 further comprises a FOV gas outlet 126. When a carrier gas is flowed through ampoule 116, the carrier gas flows over the surface of the precursor and draws vapor of the precursor through FOV gas outlet 126. Example carrier gases include nitrogen and argon. Further example carrier gases include helium, neon, krypton, and xenon.

[0057] Muti-station processing tool 100 further comprises a precursor distribution system 120 that distributes a precursor flow received from one or more precursor sources (e.g., precursor source 118) to each of processing stations 104-1 through 104-N or to exhaust system 131.

[0058] As an example, a portion of the gases from precursor distribution system 120 flows to processing station 104-1 and through the processing gas outlet 112 onto the substrate. Portions of the gases from precursor distribution system 120 also flow into each of second processing station 104-2 through Nth processing station 104-N.

[0059] As described in further detail with reference to FIG. 3, precursor distribution system 120 includes one or more dose-divert valve assemblies 130. Each dose-divert valve assembly 130 is operable to selectively direct the precursor flow received from a precursor source (e.g., 118) between a dose path fluidly coupled with two or more processing stations (e.g., 104-1 through 104-N) or a divert path fluidly coupled with exhaust system 131.

[0060] Precursor distribution system 120 can further receive a purge gas from a purge gas source 138 and direct the purge gas to each of processing stations 104-1 through 104-N. For example, a portion of the purge gas from precursor distribution system 120 flows to processing station 104-1 and through the processing gas outlet 112.

Portions of the purge gas from precursor distribution system 120 also flow into each of second processing station 104-2 through Nth processing station 104-N.

[0061] Processing tool 100 further comprises an RPG gas manifold 132 and an RPG gas distribution system 134. RPG gas manifold 132 is fluidly connected to one or more RPG gas source(s) 136 and/or purge gas source 138. Gases from RPG gas manifold 132 are directed to RPG gas distribution system 134. RPG gas distribution system 134 is configured to distribute the gas between RPGs for different processing stations (e.g. RPG 114, and RPGs for second processing station 104-2 through Nth processing station 104-N). Further, as mentioned above, some examples can omit a remote plasma generator.

[0062] Processing tool 100 further comprises a radiofrequency power source 144 electrically connected to RPG 114. Processing tool 100 further comprises a matching network 146 for impedance matching of the radiofrequency power source 144. RPG 114 can comprise a capacitively coupled plasma generator or an inductively coupled plasma generator, as examples. In other examples, RPG can comprise a microwave plasma generator.

[0063] Controller 148 is operatively coupled to controllable components of processing tool 100. For example, controller 148 is operatively coupled to substrate heater 110, RPG 114, precursor source 118, dose-divert valve assemblies (e.g., 130) of precursor distribution system 120, exhaust system 131, RPG gas manifold 132, and radiofrequency power source 144, and matching network 146. Controller 148 further can be operatively coupled to any other suitable controllable component of processing tool 100. Controller 148 is configured to control various functions of processing tool 100 to perform an ALD process.

[0064] FIGS. 2A-2H schematically depict example configurations of multi-station processing tool 100 of FIG. 1. In FIGS. 2A-2H, like numbering is used for corresponding parts in each configuration. FIG. 2A schematically depicts an example configuration in which multi-station processing tool 100 includes two processing stations 104-1 and 104-2 housed within processing chamber 102-1. In this example, a dose line 210 comprises two branches 212-1 and 212-2 that fluidly couple precursor source 118 with processing stations 104-1 and 104-2. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2.

[0065] FIG. 2B schematically depicts an example configuration in which the multi-station processing tool includes three processing stations 104-1, 104-2, and 104-3 housed within processing chamber 102-1. In this example, dose line 210 comprises three branches 212-1, 212-2, and 212-3 that fluidly couple precursor source 118 with processing stations 104-1, 104-2, and 104-3. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2. Branch 212-3 fluidly couples precursor source 118 with processing station 104-3.

[0066] FIG. 2C schematically depicts an example configuration in which the multi-station processing tool includes four processing stations 104-1, 104-2, 104-3, and 104-4 housed within processing chamber 102-1. In this example, dose line 210 comprises four branches 212-1, 212-2, 212-3, and 212-4 that fluidly couple precursor source 118 with processing stations 104-1, 104-2, 104-3, and 104-4. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2. Branch 212-3

fluidly couples precursor source 118 with processing station 104-3. Branch 212-4 fluidly couples precursor source 118 with processing station 104-4.

[0067] FIG. 2D schematically depicts an example configuration in which the multi-station processing tool includes two processing stations 104-1 and 104-2 each housed within a corresponding processing chamber of a set of two processing chambers 102-1 and 102-2. In this example, dose line 210 comprises two branches 212-1 and 212-2 that fluidly couple precursor source 118 with processing stations 104-1 and 104-2. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1 housed in processing chamber 102-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2 housed in processing chamber 102-2.

[0068] FIG. 2E schematically depicts an example configuration in which the multi-station processing tool includes three processing stations 104-1, 104-2, and 104-3 each housed within a corresponding processing chamber of a set of three processing chambers 102-1, 102-2, and 102-3. In this example, dose line 210 comprises three branches 212-1, 212-2, and 212-3 that fluidly couple precursor source 118 with processing stations 104-1, 104-2, and 104-3. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1 housed in processing chamber 102-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2 housed in processing chamber 102-2. Branch 212-3 fluidly couples precursor source 118 with processing station 104-3 housed in processing chamber 102-3.

[0069] FIG. 2F schematically depicts an example configuration in which the multi-station processing tool includes four processing stations 104-1, 104-2, 104-3, and 104-4 each housed within a corresponding processing chamber of a set of four processing chambers 102-1, 102-2, 102-3, and 102-4. In this example, dose line 210 comprises four branches 212-1, 212-2, 212-3, and 212-4 that fluidly couple precursor

source 118 with processing stations 104-1, 104-2, 104-3, and 104-4. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1 housed in processing chamber 102-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2 housed in processing chamber 102-2. Branch 212-3 fluidly couples precursor source 118 with processing station 104-3 housed in processing chamber 102-3. Branch 212-4 fluidly couples precursor source 118 with processing station 104-4 housed in processing chamber 102-4.

[0070] FIG. 2G schematically depicts an example configuration in which the multi-station processing tool includes multiple processing chambers in which each processing chamber houses multiple processing stations. For example, a first subset of the processing stations including processing stations 104-1 and 104-2 are housed in processing chamber 102-1. A second subset of the processing stations, including processing stations 104-3 and 104-4 are housed in processing chamber 102-2. It will be understood that two or more processing chambers of multi-station processing tool 100 can each have any suitable quantity of processing stations housed therein, including one, two, three, four or more processing stations. In this example, does line 210 comprises four branches 212-1, 212-2, 212-3, and 212-4 that fluidly couple precursor source 118 with processing stations 104-1, 104-2, 104-3, and 104-4. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1 housed in processing chamber 102-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2 housed in processing chamber 102-1. Branch 212-3 fluidly couples precursor source 118 with processing station 104-3 housed in processing chamber 102-2. Branch 212-4 fluidly couples precursor source 118 with processing station 104-4 housed in processing chamber 102-2.

[0071] In each of the examples of FIGS. 2A-2G, the multiple branches of dose line 210 project or otherwise extend radially outward from an upstream segment of the dose line that is centrally located among the multiple processing stations. This configuration enables the multiple branches to provide similar flow paths from precursor distribution system 120 to each of the processing stations. By providing similar flow paths among each of the multiple branches, delivery of a precursor or purge gas to the multiple processing stations by the multiple branches can be coordinated in time using an upstream dose-divert valve assembly that is shared by the multiple processing stations.

[0072] In other examples, branches of dose line 210 can have other configurations that differ from the radial configurations of FIGS. 2A-2G. FIG. 2H schematically depicts an example configuration in which the multi-station processing tool includes multiple stations 104-1 through 104-N having a generally linear arrangement, in contrast to the radial configurations of FIGS. 2A-2G. In this example, dose line 210 comprises N branches 212-1 through 212-N that fluidly couple precursor source 118 with processing stations 104-1 through 104-N. Branch 212-1 fluidly couples precursor source 118 with processing station 104-1. Branch 212-2 fluidly couples precursor source 118 with processing station 104-2. Branch 212-N fluidly couples precursor source 118 with processing station 104-N. Each of stations 104-1 through 104-N can be housed in separate processing chambers or can be housed in a shared processing chamber.

[0073] Referring briefly again to FIG. 1, precursor distribution system 120 includes one or more dose-divert valve assemblies 130. Each dose-divert valve assembly 130 is operable to selectively direct a precursor flow received from a

precursor source between a dose path fluidly coupled with two or more processing stations and a divert path fluidly coupled with exhaust system 131.

[0074] FIG. 3 schematically depicts an example configuration of precursor distribution system 120 of FIG. 1. Dose-divert valve assemblies 130-1 through 130-N include precursor inlets 310-1 through 310-N. Each precursor inlet 310-1 through 310-N is configured to receive a precursor flow from a respective precursor source 118-1 through 118-N. Here, dose-divert valve assembly 130-1 receives first precursor flow 330-1 from first precursor source 118-1 through precursor inlet 310-1. Dose-divert valve assembly 130-2 receives second precursor flow 330-2 from second precursor source 118-2 through precursor inlet 310-2. Dose-divert valve assembly 130-N receives Nth precursor flow 330-N from Nth precursor source 118-N through precursor inlet 310-N. Precursor sources 118-1 through 118-N contain different precursors in this example.

[0075] Each of dose-divert valve assemblies 130-1 through 130-N includes a dose valve operable to selectively provide the precursor flow received through the precursor inlet to a dose path. For example, dose valve 314-1 of dose-divert valve assembly 130-1 is operable to selectively provide precursor flow 330-1 received through precursor inlet 310-1 to dose path 316-1. Dose valve 314-1 of dose-divert valve assembly 130-2 is operable to selectively provide precursor flow 330-2 received through precursor inlet 310-2 to dose path 316-2. Dose valve 314-N of dose-divert valve assembly 130-N is operable to selectively provide precursor flow 330-N received through precursor inlet 310-N to dose path 316-N.

[0076] Each of dose-divert valve assemblies 130-1 through 130-N includes a divert valve operable to selectively provide the precursor flow received through precursor inlet to a divert path. For example, divert valve 318-1 of dose-divert valve

assembly 130-1 is operable to selectively provide precursor flow 330-1 received through precursor inlet 310-1 to divert path 320-1. Divert valve 318-2 of dose-divert valve assembly 130-2 is operable to selectively provide precursor flow 330-2 received through precursor inlet 310-2 to divert path 320-2. Divert valve 318-N of dose-divert valve assembly 130-N is operable to selectively provide precursor flow 330-N received through precursor inlet 310-N to divert path 320-N.

[0077] Dose valve 314-1 and divert valve 318-1 of valve assembly 130-1 are independently operable. For example, controller 148 can control dose valve 314-1 to open or close independent of divert valve 318-1. Similarly, dose valves and divert valves of valve assemblies 130-2 through 130-N are independently operable. Accordingly, each of dose-divert valve assemblies 130-1 through 130-N is operable to selectively direct a respective precursor flow received from a respective precursor source between the dose path or the divert path of the valve assembly. For example, dose-divert valve assembly 130-1 is operable to selectively direct precursor flow 330-1 received from precursor source 118-1 to dose path 316-1 by opening dose valve 314-1 and closing divert valve 318-1. Dose-divert valve assembly 130-1 is operable to selectively direct precursor flow 330-1 received from precursor source 118-1 to divert path 320-1 by closing dose valve 314-1 and opening divert valve 318-1. Dose-divert valve assemblies 130-2 through 130-N can be similarly operated to direct their respective precursor flows between the dose path or the divert path of the valve assembly.

[0078] Precursor distribution system 120 further comprises dose line 210 comprising two or more branches 212-1 through 212-N. Branch N indicates an optional one or more branches in addition to branches 212-1 and 212-2. Example configurations of dose line 210 are described with reference to FIGS. 2A – 2H. Dose

line 210 is connected to each of dose valve 314-1 through 314-N of dose-divert valve assemblies 130-1 through 130-N. For example, dose line 210 is fluidly coupled to each of dose paths 316-1 through 316-N by a dose manifold 340 of precursor distribution system 120. In this example, dose paths 316-1 through 316-N collectively comprise or form part of dose manifold 340 to which each dose-divert valve assemblies 130-1 through 130-N are fluidly coupled. For example, first dose-divert valve assembly 130-1, second dose-divert valve assembly 130-2 and Nth dose-divert valve assembly 130-N are fluidly coupled with dose line 210 by dose manifold 340.

[0079] Branches 212-1 through 212-N of dose line 210 are fluidly coupled with corresponding processing stations 104-1 through 104-N of multi-station processing tool 100. For example, branch 212-1 is fluidly coupled with processing station 104-1 by processing gas outlet 112-1. Branch 212-2 is fluidly coupled with processing station 104-2 by processing gas outlet 112-2. Branch 212-N is fluidly coupled with processing station 104-N by processing gas outlet 112-N.

[0080] Dose manifold 340 further includes a purge gas inlet 342 to receive purge gas from purge gas source 138. As an example, purge gas inlet 342 can be located upstream of fluid connections of dose manifold 340 with respective dose valves 314-1 through 314-N of dose-divert valve assemblies 130-1 through 130-N.

[0081] Divert paths 320-1 through 320-N collectively comprise or form part of a divert manifold 344 to which dose-divert valve assemblies 130-1 through 130-N are fluidly coupled. In this example, multi-station processing tool 100 further comprises a divert line 346 connected to divert manifold 344. Divert line 346 fluidly couples divert manifold 344 with exhaust system 131, as an example.

[0082] The configuration of FIG. 3 offers advantages over the use of station-specific dose valves and station-specific divert valves. For example, in a processing

system with four processing stations, four dose valves and four divert valves would be used where station-specific dose-divert valves are used. In contrast, precursor distribution system 120 can serve four processing stations with dose-divert valve assembly 130-1 that includes dose valve 314-1 and divert valve 318-1. In this example, precursor distribution system 120 utilizes two valves as compared to the eight valves of the other multi-station processing tools.

[0083] Furthermore, in other multi-station processing tools that include station-specific dose and divert valves, multiple precursor sources can share a common supply line used to deliver precursor to each of the station-specific dose and divert valves. In this configuration, precursor flow control valves for each precursor source can be used. In contrast, precursor distribution system 120 can avoid the use of separate precursor flow control valves, as the dose-divert valve assemblies 130-1 through 130-N isolate each precursor source from each other precursor source. For a multi-station processing tool comprising two precursor sources and four stations that utilizes station-specific dose-divert valve assemblies, a total of four dose valves, four divert valves, and two precursor source valves would be used. In contrast, for a multi-station processing tool that uses a single dose-divert valve assembly for each precursor source, a total of two dose valves and two divert valves can be used.

[0084] The placement of dose-divert valve assemblies 130-1 through 130-N upstream of branches in dose line 210 can lead to a delay between opening of dose valves 314-1 through 314-N and delivery of the precursor to processing stations 104-1 through 104-N compared to the use of station-specific dose-divert valves. Such delay in precursor flow can be addressed by advancing an opening timing of the dose valve in relation to the dose phase. Additionally or alternatively, such delay in precursor flow can be addressed by increasing a pressure differential between the precursor flow and

the chamber pressure within the processing chamber. Additionally or alternatively, such delay in precursor flow can be addressed by reducing a cross-sectional area of dose line 210 and its branches 212-1 through 212-N. Control of the opening timing of the dose valve and the pressure differential of the precursor flow are described in further detail with reference to method 500 of FIG. 5.

[0085] FIG. 4 depicts an example of a portion of precursor distribution system 120 according to the configuration of FIG. 3 in which various components are integrated with a manifold body 400. Manifold body 400 includes interior pathways that define dose manifold 340 and divert manifold 344, previously described with reference to FIG. 3. In this example, manifold body 400 supports distribution of two precursors received from two precursor sources. It will be understood that manifold body 400 can support distribution of precursors received from any suitable quantity precursor sources (e.g., 118-1 through 118-N).

[0086] Dose valve 314-1 and divert valve 318-1 are mounted to manifold body 400. Additionally, in this example, dose valve 314-2 and divert valve 318-2 also are mounted to manifold body 400. Manifold body 400 further provides an opening for precursor inlets 310-1 and 310-2 of dose-divert valve assemblies 130-1 and 130-2. In this example, the openings for the precursor inlets 310-1 and 310-2 are located along a rear side of manifold body 400 and are depicted schematically in FIG. 4 using broken lines. Manifold body 400 includes purge gas inlet 342 by which purge gas can be received. Manifold body 400 includes a dose outlet 410 by which dose manifold 340 can be fluidly coupled with dose line 210 of FIG. 3. In this example, dose outlet 410 is located along a rear side of manifold body 400 and is depicted schematically in FIG. 4 using broken lines. Manifold body 400 further includes a divert outlet 412 by which divert manifold 344 is fluidly coupled with divert line 346 of FIG. 3.

[0087] FIG. 5 is a flow diagram depicting an example method 500 of operating a precursor delivery system for a multi-station processing tool. As an example, method 500 can be performed by controller 148 at any of dose-divert valve assemblies 130-1 through 130-N of FIG. 3. The dose-divert valve assembly is operable to selectively direct a precursor flow received from a precursor source between a dose path fluidly coupled with two or more processing stations of the multi-station processing tool or a divert path. As previously described with reference to FIG. 3, the dose-divert valve assembly includes a dose valve and a divert valve.

[0088] At 510, the method comprises obtaining a dose phase timing value indicating a target dose phase timing for delivery of the precursor flow of the precursor source to the two or more processing chambers. For example, controller 148 can obtain the dose phase timing value from an ALD recipe stored in memory of the controller.

[0089] At 512, the method comprises obtaining a dose duration value indicating a target dose duration of time for opening of a dose valve of the dose-divert valve assembly. For example, controller 148 can obtain the dose duration value from the ALD recipe stored in memory of the controller. In some examples, the target dose duration of time can be based on a pressure differential between a chamber pressure within a processing chamber where the precursor flow is to be delivered and a target pressure differential of the precursor flow above the chamber pressure.

[0090] At 514, the method comprises, in advance of the dose valve being controlled to open, providing the precursor flow to the dose-divert valve assembly as a charge volume at a target pressure differential above the chamber pressure within one or more processing chambers housing the two or more processing stations.

[0091] At 516, the method comprises controlling the dose valve of the dose-divert valve assembly to open for the target dose duration of time in advance of the dose

phase of the two or more processing stations to provide the precursor flow to the dose path.

[0092] At 518, the method comprises controlling the divert valve to close during at least a portion of time that the dose valve is controlled to open. In some examples, the divert valve is maintained in a closed state for the duration of time that the dose valve is controlled to open.

[0093] At 520, the method comprises controlling the dose valve to close upon conclusion of the target dose duration.

[0094] At 522, the method comprises controlling the divert valve of the dose-divert valve assembly to open at a target divert timing in relation to the conclusion of the target dose duration to provide the precursor flow to the divert path.

[0095] Method 500 can be performed for each precursor source of multiple precursor sources using a dose-divert valve assembly that corresponds to the precursor source. Additionally, it will be understood that method 500 can be performed repeatedly over a plurality of ALD cycles.

[0096] FIG. 6 schematically shows an example computing system 600 that can enact one or more of the methods, processes, and other control operations described herein. Computing system 600 is shown in simplified form. Computing system 600 can take the form of one or more personal computers, workstations, computers integrated with substrate processing tools, and/or network accessible server computers.

[0097] Computing system 600 includes a logic subsystem 602 and a storage subsystem 604. Computing system 600 can optionally include a display subsystem 606, input subsystem 608, communication subsystem 610, and/or other components not shown in FIG. 6. Controller 148 of FIG. 1 is an example of computing system 600.

[0098] Logic subsystem 602 includes one or more physical devices configured to execute instructions. For example, the logic subsystem can be configured to execute instructions that are part of one or more applications, services, programs, routines, libraries, objects, components, data structures, or other logical constructs. Such instructions can be implemented to perform a task, implement a data type, transform the state of one or more components, achieve a technical effect, or otherwise arrive at a desired result.

[0099] The logic subsystem can include one or more processors configured to execute software instructions. Additionally or alternatively, the logic subsystem can include one or more hardware or firmware logic subsystems configured to execute hardware or firmware instructions. Processors of the logic subsystem can be single-core or multi-core, and the instructions executed thereon can be configured for sequential, parallel, and/or distributed processing. Individual components of the logic subsystem optionally can be distributed among two or more separate devices, which can be remotely located and/or configured for coordinated processing. Aspects of the logic subsystem can be virtualized and executed by remotely accessible, networked computing devices configured in a cloud-computing configuration.

[00100] Storage subsystem 604 includes one or more physical devices configured to hold instructions 612 executable by the logic subsystem to implement the methods, processes, and other control operations described herein. When such methods, processes, and control operations are implemented, the state of storage subsystem 604 can be transformed—e.g., to hold different data.

[00101] Storage subsystem 604 can include removable and/or built-in devices. Storage subsystem 604 can include optical memory (e.g., CD, DVD, HD-DVD, Blu-Ray Disc, etc.), semiconductor memory (e.g., RAM, EPROM, EEPROM, etc.), and/or

magnetic memory (e.g., hard-disk drive, floppy-disk drive, tape drive, MRAM, etc.), among others. Storage subsystem 604 can include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, location-addressable, file-addressable, and/or content-addressable devices.

[00102] It will be appreciated that storage subsystem 604 includes one or more physical devices. However, aspects of the instructions described herein alternatively can be propagated by a communication medium (e.g., an electromagnetic signal, an optical signal, etc.) that is not held by a physical device for a finite duration.

[00103] Aspects of logic subsystem 602 and storage subsystem 604 can be integrated together into one or more hardware-logic components. Such hardware-logic components can include field-programmable gate arrays (FPGAs), program- and application-specific integrated circuits (ASIC / ASICs), program- and application-specific standard products (PSSP / ASSPs), system-on-a-chip (SOC), and complex programmable logic devices (CPLDs), for example.

[00104] When included, display subsystem 606 can be used to present a visual representation of data held by storage subsystem 604. This visual representation can take the form of a graphical user interface (GUI). As the herein described methods, processes, and other control operations change the data held by the storage subsystem, and thus transform the state of the storage subsystem, the state of display subsystem 606 can likewise be transformed to visually represent changes in the underlying data. Display subsystem 606 can include one or more display devices utilizing virtually any type of technology. Such display devices can be combined with logic subsystem 602 and/or storage subsystem 604 in a shared enclosure, or such display devices can be peripheral display devices.

[00105] When included, input subsystem 608 can comprise or interface with one or more user-input devices such as a keyboard, mouse, or touch screen. In some examples, the input subsystem can comprise or interface with selected natural user input (NUI) componentry. Such componentry can be integrated or peripheral, and the transduction and/or processing of input actions can be handled on- or off-board. Example NUI componentry can include a microphone for speech and/or voice recognition, and an infrared, color, stereoscopic, and/or depth camera for machine vision and/or gesture recognition.

[00106] When included, communication subsystem 610 can be configured to communicatively couple computing system 600 with one or more other computing devices. Communication subsystem 610 can include wired and/or wireless communication devices compatible with one or more different communication protocols. As non-limiting examples, the communication subsystem can be configured for communication using a wireless telephone network, or a wired or wireless local- or wide-area network. In some examples, the communication subsystem can allow computing system 600 to send and/or receive messages to and/or from other devices using a network such as the Internet.

[00107] It will be understood that the configurations and/or approaches described herein are exemplary in nature, and that these specific examples or examples are not to be considered in a limiting sense, because numerous variations are possible. The specific routines or methods described herein can represent one or more of any number of processing strategies. As such, various acts illustrated and/or described can be performed in the sequence illustrated and/or described, in other sequences, in parallel, or omitted. Likewise, the order of the above-described processes can be changed.

[00108] The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various processes, systems and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as any and all equivalents thereof.

CLAIMS:

1. A multi-station processing tool, comprising:
 - two or more processing stations;
 - a precursor source;
 - a dose-divert valve assembly operable to selectively direct a precursor flow received from the precursor source between a dose path or a divert path, wherein the dose-divert valve assembly includes:
 - a precursor inlet to receive the precursor flow from the precursor source,
 - a dose valve operable to selectively provide the precursor flow to the dose path, and
 - a divert valve operable to selectively provide the precursor flow to the divert path; and
 - a dose line comprising two or more branches, the dose line connected to the dose valve and each branch of the dose line to be fluidly coupled with a corresponding processing station of the two or more processing stations.
2. The multi-station processing tool of claim 1, wherein the dose-divert valve assembly is a first dose-divert valve assembly, wherein the dose path comprises a dose manifold to which the first dose-divert valve assembly is fluidly coupled, wherein the precursor source is a first precursor source, and wherein the multi-station processing tool further comprises:
 - a second precursor source; and
 - a second dose-divert valve assembly fluidly coupled with the second precursor source and with the dose manifold.

3. The multi-station processing tool of claim 2, wherein the dose manifold further includes a purge gas inlet to receive a purge gas from a purge gas source.
4. The multi-station processing tool of claim 2, wherein the divert path comprises a divert manifold to which the first dose-divert valve assembly and the second dose-divert valve assembly are fluidly coupled, and wherein the multi-station processing tool further comprises:
 - a divert line connected to the divert manifold.
5. The multi-station processing tool of claim 1, wherein the multi-station processing tool comprises four or more processing stations, and wherein the dose line comprises four or more branches.
6. The multi-station processing tool of claim 1, wherein the two or more branches project radially outward from an upstream segment of the dose line.
7. The multi-station processing tool of claim 1, wherein the two or more processing stations are housed in a same processing chamber.
8. The multi-station processing tool of claim 1, wherein a first processing station of the two or more processing stations is housed in a first processing chamber, and wherein a second processing station of the two or more processing stations is housed in a second processing chamber.

9. The multi-station processing tool of claim 1, further comprising a controller configured to control an opening timing and a closing timing of the dose valve, and control an opening timing and a closing timing of the divert valve.

10. A precursor distribution system for a multi-station processing tool, the system comprising:

a dose-divert valve assembly operable to selectively direct a precursor flow received from a precursor source between a dose path or a divert path, wherein the dose-divert valve assembly includes:

a precursor inlet to receive the precursor flow from the precursor source,

a dose valve operable to selectively provide the precursor flow to the dose path, and

a divert valve operable to selectively provide the precursor flow to the divert path; and

a dose line comprising two or more branches, the dose line configured to be connected to the dose valve and each branch of the dose line configured to be fluidly coupled with a corresponding processing station of two or more processing stations of the multi-station processing tool.

11. The system of claim 10, wherein the dose-divert valve assembly is a first dose-divert valve assembly, wherein the precursor source is a first precursor source, and wherein the system further comprises:

a second dose-divert valve assembly operable to selectively direct a second precursor flow received from a second precursor source between a second dose path or a second divert path, wherein the second dose-divert valve assembly includes:

a second precursor inlet to receive the second precursor flow from the second precursor source,

a second dose valve operable to selectively provide the second precursor flow from the second precursor source to the second dose path, and

a second divert valve operable to selectively provide the second precursor flow from the second precursor source to the second divert path.

12. The system of claim 11, wherein the dose path of the first dose-divert valve assembly comprises a dose manifold to which the first dose-divert valve assembly and the second dose-divert valve assembly are coupled.

13. The system of claim 12, wherein the dose manifold further includes a purge gas inlet to receive a purge gas from a purge gas source.

14. The system of claim 11, further comprising a divert manifold to which the first dose-divert valve assembly and the second dose-divert valve assembly are fluidly coupled, and wherein the system further comprises a divert line configured to be connected to the divert manifold.

15. The system of claim 14, wherein the divert path of the first dose-divert valve assembly and the second divert path of the second dose-divert valve assembly comprise the divert manifold.

16. The system of claim 10, wherein the dose line comprises four or more branches for four or more corresponding processing stations.

17. The system of claim 10, wherein the two or more branches project radially outward from an upstream segment of the dose line.

18. The system of claim 10, wherein the dose valve and the divert valve are independently operable.

19. A method of operating a precursor delivery system for a multi-station processing tool, the method comprising:

controlling a dose valve of a dose-divert valve assembly to open for a target dose duration of time in advance of a dose phase of two or more processing stations to provide a precursor flow to a dose path;

controlling the dose valve to close upon conclusion of the target dose duration; and

controlling a divert valve of the dose-divert valve assembly to open at a target divert timing in relation to the conclusion of the target dose duration to provide the precursor flow to a divert path.

20. The method of claim 19, further comprising:

in advance of the dose valve being controlled to open, providing the precursor flow to the dose-divert valve assembly as a charge volume at a target pressure differential above a chamber pressure within one or more processing chambers housing the two or more processing stations.