

ACTIVE DIVERT PRESSURE TUNING

INCORPORATION BY REFERENCE

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

BACKGROUND

[0002] Semiconductor manufacturing typically involves one or more processing operations to, for example, deposit and/or etch a structure on or in a semiconductor wafer (or substrate). For instance, a typical processing operation may involve a substrate being supported on a pedestal in a process chamber and one or more process gases being flowed into the process chamber via a gas distributor to bring about a desired effect, such as the deposition of a layer of material onto the substrate. In some cases, a processing operation may employ one or more precursor delivery systems in which vapor phase (and/or sometimes gaseous) precursors are reacted with and/or on a substrate surface to deposit material thereon or to remove material therefrom. Although many forms of precursor delivery systems exist, they are generally configured to provide controlled gas flow and delivery of precursors, which may otherwise be in a gaseous, liquid, or solid phase at ambient temperature and atmospheric pressure conditions. It is noted that tetramethylsilane (4MS) is one type of precursor that is sometimes used to deposit carbon-doped silicon films and silicon carbide-like films onto a substrate and has a liquid phase at ambient temperature and atmospheric pressure conditions, but may be delivered to a process chamber in a vapor phase. Similar vapor phase delivery may be utilized in association with, for instance, molybdenum hexacarbonyl, which has a solid phase at ambient temperature and atmospheric pressure conditions. Silane is an example of a precursor typically used to form oxide, nitride, and polysilicon films and has a gaseous phase at ambient temperature and atmospheric pressure conditions, and to this end, may be delivered to a process chamber in a gaseous phase. However, as semiconductor manufacturing scales to meet consumer demand, the viability of a processing operation (especially one involving the use of a precursor) may depend not only upon the rate at which such a processing operation may be performed, but also the amount of resources the processing operation wastes.

[0003] The background provided herein is for the purposes of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent that it is described in this background, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the disclosure.

SUMMARY

[0004] Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. The following, non-limiting implementations are considered part of the disclosure; other implementations will be evident from the entirety of this disclosure and the accompanying drawings as well.

[0005] Some aspects provide various systems, apparatuses, and techniques for adjusting and equalizing flow conditions (e.g., pressure) between various conduits as part of flowing one or more precursors in a vapor and/or gaseous phase in association with a semiconductor processing operation.

[0006] Additional aspects will be set forth in the detailed description which follows, and, in part, will be apparent from the disclosure, or may be learned by practice of the disclosed aspects and/or the claimed subject matter.

[0007] According to an aspect, an apparatus for semiconductor processing may include a junction point, a gas delivery system, a precursor delivery system, a divert valve, and a pressure regulator. The gas delivery system is fluidically connected with the junction point via a first conduit. The gas delivery system is configured to supply at least one process gas to the junction point. The precursor delivery system is fluidically connected with the junction point via a second conduit. The precursor delivery system is configured to supply at least one precursor to the junction point in a vapor and/or gaseous phase. The divert valve includes a first inlet fluidically connected with the precursor delivery system via a third conduit, a first outlet fluidically connected with the junction point via the second conduit, and a second outlet fluidically connected with an exhaust via a fourth conduit. The pressure regulator fluidically interposed between the second outlet and the exhaust, the pressure regulator being configured to control pressure in at least a portion of the fourth conduit based on pressure in the first conduit.

[0008] According to some aspects, the portion of the fourth conduit may be fluidically interposed between the divert valve and the pressure regulator.

[0009] According to some aspects, the control of the pressure in the portion of the fourth conduit may be configured to cause, at least in part, the pressure in the portion of the fourth conduit to increase and equalize with the pressure in the first conduit within a determined margin of error.

[0010] According to some aspects, the apparatus may further include at least one controller and a first pressure transducer. The at least one controller may be operatively connected with the pressure regulator. The first pressure transducer may be fluidically connected with the first conduit and may be communicatively coupled with the at least one controller. The first pressure transducer may be configured to provide first information to the at least one controller corresponding to the pressure in the first conduit. The at least one controller may be configured to receive the first information from the first pressure transducer, and control operation of the pressure regulator based on the first information.

[0011] According to some aspects, the first pressure transducer may be arranged in association with a portion of the first conduit fluidically interposed between the gas delivery system and the junction point.

[0012] According to some aspects, the at least one controller may be configured to convert the first information into a variable control signal, and apply the variable control signal to the pressure regulator.

[0013] According to some aspects, the variable control signal may be at least partially defined by a ramp function.

[0014] According to some aspects, the apparatus may further include a second pressure transducer fluidically connected with the fourth conduit and communicatively coupled with the at least one controller. The second pressure transducer may be configured to provide second information to the at least one controller corresponding to the pressure in at least the portion of the fourth conduit. The at least one controller may be configured to receive the second information from the second pressure transducer, and control operation of the pressure regulator based further on the second information.

[0015] According to some aspects, the second pressure transducer may be arranged in association with the portion of the fourth conduit.

[0016] According to some aspects, the at least one controller may include a proportional-integral-derivative controller.

[0017] According to some aspects, the at least one controller may include a pressure controller and a process controller. The pressure controller may be operatively connected with the pressure regulator and may be configured to control the operation of the pressure regulator based on first control information. The process controller may be communicatively coupled with the pressure controller and the first pressure transducer. The process controller may be configured to receive the first information from the first pressure transducer, process the first information to generate the first control information, and transmit the first control information to the pressure controller.

[0018] According to some aspects, the pressure controller, the pressure regulator, and the second pressure transducer may form portions of a same structure that is distinct from a structure including the process controller.

[0019] According to some aspects, the pressure regulator may include a proportional control valve, and the second pressure transducer may include a capacitance manometer.

[0020] According to some aspects, the first information may include an analog voltage signal, and the first control information may include either an analog signal or a digital signal.

[0021] According to some aspects, the pressure controller may be configured to transmit the second information to the process controller, and the process controller may be configured to generate the first control information based further on the second information.

[0022] According to some aspects, as part of the generation of the first control information, the process controller may be configured to determine an average of the first information over a determined period of time and utilize the average to generate the first control information.

[0023] According to some aspects, the process controller may be operatively connected with the divert valve and may be configured to control operation of the divert valve according to a semiconductor process recipe.

[0024] According to some aspects, as part of the semiconductor process recipe, the process controller may be configured to cause, at least in part, the divert valve to toggle between a first open configuration and a second open configuration. In the first open configuration, the divert valve may be configured to fluidically connect the precursor delivery system with the exhaust. In the second open configuration, the divert valve may be configured to fluidically connect the precursor delivery system with the junction point. The pressure in the portion of the fourth conduit may be caused, at least in part, to be equalized with the pressure in the first conduit within the determined margin of error prior to the divert valve being toggled from the

first open configuration to the second open configuration.

[0025] According to some aspects, the apparatus may further include at least one control valve fluidically connected with the second conduit and fluidically interposed between the divert valve and the junction point. In a closed configuration of the at least one control valve, a pressure in at least a portion of the second conduit may be caused, at least in part, to be maintained at the pressure in the first conduit within a determined margin of error.

[0026] According to some aspects, the process controller may be operatively coupled with the at least one control valve. As part of the semiconductor process recipe, the process controller may be configured to cause, at least in part, the at least one control valve to toggle from the closed configuration to an open configuration. In the open configuration, the at least one control valve may be configured to fluidically connect the precursor delivery system with the junction point. In the closed configuration, the at least one control valve may be configured to block a flow of the at least one precursor in the vapor and/or gaseous phase to junction point. The pressure in the portion of the fourth conduit may be caused, at least in part, to be equalized with the pressure in the first conduit within the determined margin of error and the divert valve may be caused, at least in part, to be toggled from the first open configuration to the second open configuration prior to the at least one control valve being toggled from the closed configuration to the open configuration.

[0027] According to some aspects, the apparatus may further include a first inlet control valve and a second inlet control valve. The first inlet control valve may be fluidically interposed between the precursor delivery system and the first inlet of the divert valve. The second inlet control valve may be fluidically interposed between a source of purge gas and the first inlet of the divert valve. The first inlet control valve may be configured, when in a closed configuration, to block a flow of the at least one precursor in the vapor and/or gaseous phase to the divert valve. The second inlet control valve may be configured, when in an open configuration, to cause, at least in part, the purge gas to flow in at least one of the second conduit and the fourth conduit when the first inlet control valve is in the closed configuration and the divert valve is in at least one open configuration.

[0028] According to some aspects, the divert valve may include a three-way control valve. The junction point may include at least one of a gas mixing bowl, a charge plenum, and a multiway conduit fitting.

[0029] According to some aspects, the apparatus may further include a gas filter fluidically interposed between the divert valve and the junction point. The gas filter may be configured

to remove particulate matter from a flow of the at least one precursor in the vapor and/or gaseous phase prior to the flow being input to junction point.

[0030] According to some aspects, the at least one control valve may include a first control valve fluidically connected with the first outlet of the divert valve, and a second control valve fluidically interposed between the first control valve and the junction point. The gas filter may be fluidically interposed between the first control valve and the second control valve.

[0031] According to some aspects, the at least one control valve may further include a third control valve. The third control valve may be fluidically interposed between the first outlet of the divert valve and the first control valve.

[0032] According to some aspects, the apparatus may further include a process chamber and a gas distributor. The gas distributor may be fluidically connected with the junction point. The gas distributor may be configured to distribute either or both of the at least one process gas and the at least one precursor in the vapor and/or gaseous phase in the process chamber in response to reception of a corresponding flow of the at least one process gas and/or the precursor in the vapor and/or gaseous phase.

[0033] According to some aspects, the apparatus may further include a radio frequency (“RF”) generator communicatively coupled with the process controller and configured to apply RF power to the gas distributor to generate plasma in the process chamber while the precursor in the vapor and/or gaseous phase is caused, at least in part, to be distributed in the process chamber.

[0034] The foregoing general description and the following detailed description are illustrative and explanatory and are intended to provide further explanation of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] Various aspects disclosed herein are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings, in which like reference numerals refer to similar elements.

[0036] FIG. 1 is a reference plot of pressure as a function of time for a main gas supply line and a divert of a conventional semiconductor processing system.

[0037] FIG. 2 schematically illustrates a semiconductor processing system not only capable of processing a semiconductor, but also capable of controlling pressure in a divert line based on pressure in a main gas supply line according to some aspects.

[0038] FIG. 3 schematically illustrates a portion of a gas delivery network of the semiconductor processing system of FIG. 2 according to some aspects.

[0039] FIG. 4 is a reference plot of pressure as a function of time at least for a main gas supply line and a divert line of the semiconductor processing system of FIG. 2 including the portion of the gas delivery network of FIG. 3 according to some aspects.

[0040] FIGS. 5 and 6 are flowcharts of processes for actively controlling the pressure of a portion of a divert line based on the pressure in a main gas supply line according to some aspects.

[0041] FIG. 7 schematically illustrates a multi-station processing tool according to some aspects.

DETAILED DESCRIPTION

[0042] In the following description, numerous specific details are set forth in order to provide a thorough understanding of various aspects. The disclosed aspects may be practiced without some or all of these specific details. In other instances, well-known process operations have not been described in detail to not unnecessarily obscure the disclosed aspects. While the disclosed aspects will be described in conjunction with specific implementations, it will be understood that it is not intended to limit the disclosed aspects.

[0043] In this application, the terms “semiconductor wafer,” “wafer,” “substrate,” “wafer substrate” and “partially fabricated integrated circuit” are used interchangeably. One of ordinary skill in the art would understand that the term “partially fabricated integrated circuit” can refer to a silicon wafer during any of many stages of integrated circuit fabrication thereon. A wafer or substrate used in the semiconductor device industry typically has a diameter of 200 mm, or 300 mm, or 450 mm. In addition to semiconductor wafers, other work pieces that may take advantage of the disclosed aspects include various articles, such as printed circuit boards, magnetic recording media, magnetic recording sensors, mirrors, optical elements, micro-mechanical devices, and the like.

Context

[0044] Semiconductor wafers are frequently processed inside of process chambers through operations that may include exposing the semiconductor wafers to one or more gas(es). A process chamber may be fluidically connected with a gas distribution network, which may include one or more gas sources, manifolds, conduits, junctions, fittings, gas distributors (such as a showerhead), and the like, that deliver the gas(es) to a semiconductor wafer located

within the process chamber. The gas(es) used to process a substrate during various processing stages may include, for example, process gas(es), carrier gas(es), precursor(s) (gaseous and/or vaporized liquid and/or solid), purge gas(es), etc. The gas distribution network may include a combination of one or more flow paths and plenums and may, for example, be designed to mix gases, e.g., mix a precursor with a carrier gas, mix two or more gases, mix one or more gases with one or more reactant species, and/or the like, before flowing the gases to, for instance, a showerhead for distribution relative to (e.g., over, on, and/or under) the substrate. In some cases, the gas distribution network may be configured to toggle the delivery of one or more gases between a main gas supply line (which may be interchangeably referred to, herein, as a channel, conduit, passageway, pipe, or other like terminology) fluidically connected with the gas distributor and a divert line (which may also be interchangeably referred to, herein, as a channel, conduit, passageway, pipe, or other like terminology) fluidically connected with a vacuum or other exhaust. This switching may be facilitated using a divert, which may include one or more control valves fluidically connected with the main gas supply line and the divert line. It is noted, however, that disparate flow conditions existing in the main gas supply line relative to the divert line when the flow of the gas(es) are toggled from the divert line to the main gas supply line by the divert may cause, at least in part, added processing time to be expended to allow the flow conditions to sufficiently stabilize, and thereby, allow the gas(es) to flow into the main gas supply line from the divert. Additional resources may also be depleted during this stabilization period. The effect of these flow conditions will be described in more detail in association with FIG. 1 and in the context of a pressure difference between the main gas supply line and the divert line. FIG. 1 is a reference plot of pressure as a function of time for a main gas supply line and a divert of a conventional semiconductor processing system.

[0045] As previously noted, some semiconductor processing operations may employ one or more precursor delivery systems in which, for example, vapor phase and/or sometimes gas precursors (hereinafter, collectively or individually referred to as “precursor vapor,” “precursor gas,” or “precursor in a vapor phase”) are reacted with and/or on a substrate surface to deposit material thereon or remove material therefrom. To help ensure a consistent flow of precursor gas to a process chamber, some gas delivery networks may use a divert to vacuum operation, which initially flows precursor gas to vacuum to establish a precursor vapor prior to flowing the precursor gas to the process chamber. It is noted, however, that there can be a noticeable delay in the delivery of the precursor vapor to the process

chamber when the flow of the precursor vapor is switched from flowing to vacuum to flowing to the process chamber by, for example, a divert valve. In some cases, the delay may be caused, at least in part, by a mismatch in pressure between the divert line (and, thereby, the divert valve) and the main gas supply line when the switching operation is performed. For instance, if the divert line (and, thereby, the divert valve) is at a lower pressure than the main gas supply line, there can be a delay (such as a several second delay) during which time the pressure in at least the divert valve equalizes with the pressure in the main gas supply line to which the divert valve is fluidically connected. This equalization in pressure will allow the precursor vapor to flow into the main gas supply line. It is noted, however, that the time consumed for this pressure equalization to occur may not only increase the amount of time having to be allotted to an associated semiconductor processing operation, but may also increase the amount of resources expended waiting for the flow of precursor vapor to stabilize in the main gas supply line.

[0046] For example, as seen in FIG. 1, during an initial period at least between times t_1 and t_2 , one or more first gases may be flowed to a process chamber using a main gas supply line at a first pressure (or within a first pressure range), such as between about 125 Torr and about 175 Torr, e.g., at about 150 Torr. Pressure in the main gas supply line is depicted in FIG. 1 via plot line 101. During this initial period, precursor vapor may be flowed to vacuum using a divert fluidically connected to vacuum via a divert line at a second pressure (or within a second pressure range), such as between about 25 Torr and about -25 Torr, for instance, at about 0 Torr. During this initial period, pressure in the divert will correspond with pressure in the divert line to which the divert is fluidically connected. Pressure in the divert is conveyed in FIG. 1 via plot line 103. At or near time t_2 , the flow of the precursor vapor may be switched by the divert from the divert line to the main gas supply line. Given that the divert may be at a lower pressure than the main gas supply line when the flow of the precursor vapor is switched to the main gas supply line, pressure in the main gas supply line may experience pressure perturbation 105 as the pressure in the divert equalizes with pressure in the main gas supply line. That is, the pressure in the main gas supply line may initially decrease and then increase to stabilize back at the first pressure while the pressure in the divert increases from the second pressure to the first pressure. In some cases, pressure perturbation 105 may be indicative of flow from the main gas supply line at least towards the divert. It is also noted that the pressure difference between the divert and the main gas supply line may cause, at least in part, the formation of a barrier to the flow of the precursor vapor

into the main gas supply line, and the barrier may exist until the pressure differential is substantially resolved or at least overcome. Period 107 may correspond to a time delay associated with the equalization process or at least a duration of time before precursor vapor is able to flow into the main gas supply line as the pressure in the divert may exceed the pressure in the main gas supply line as a flow rate of the precursor vapor from a precursor vapor source is variably increased to a third pressure (or within a third pressure range), which may be greater than or equal to the first pressure. For instance, the third pressure may be between about 200 Torr and about 300 Torr, e.g., about 250 Torr. Period 109 may correspond to a stabilization period during which time the flow rate of the precursor vapor continues to increase and an associated pressure in the divert stabilizes at the third pressure. It is noted, however, that one or more other flow components may cause, at least in part, the pressure in the main gas supply line to remain at or near the first pressure despite an increase in pressure associated with the flow of the precursor vapor. For instance, mixing of the precursor vapor and one or more gases supplied via the main gas supply line in a junction point fluidically connected with the divert and the main gas supply line may cause, at least in part, pressure in the main gas supply line to remain at or near the first pressure. It is also noted that during periods 107 and 109, a flow of the vapor precursor to the process chamber may be flowed to vacuum, and thereby, wasted until the flow of the vapor precursor stabilizes. As such, time and resources may be expended during the aforementioned processes.

[0047] According to some aspects, various systems, apparatuses, and techniques may be employed to regulate (e.g., equalize or substantially equalize) flow conditions (e.g., pressure) in at least one conduit (e.g., a divert line) based on flow conditions in at least one other conduit (e.g., a main gas supply line) as part of flowing one or more precursor vapors to a process chamber in association with a semiconductor processing operation. In some implementations, pressure in the divert line may be actively controlled via one or more pressure regulators based on pressure in the main gas supply line prior to (and/or as part of) a flow of precursor vapor being switched from vacuum to the main gas supply line by a divert. In some cases, the pressure regulator may be an inline, electronic pressure regulator, but implementations are not limited thereto. Whatever the case, active control of the pressure in the divert line may effectively eliminate or at least reduce a delay between the time at which the divert switches the flow of precursor vapor to the main gas supply line from vacuum and the time at which the precursor vapor flows into the main gas supply line. With the

elimination or at least reduction in this delay, not only may a throughput of an associated semiconductor processing operation be increased, but associated costs and resource expenditures may be reduced.

Systems for Semiconductor Processing

[0048] FIG. 2 schematically illustrates a semiconductor processing system not only capable of processing a semiconductor, but also capable of controlling pressure in a divert line based on pressure in a main gas supply line according to some aspects.

[0049] Referring to FIG. 2, substrate processing system (or system) 200 is shown as an example. Although various implementations will be described in the context of chemical vapor deposition (CVD) and/or plasma-enhanced CVD (PECVD), aspects are not limited thereto. For instance, substrate processing system 200 may be utilized in the context of atomic layer deposition (ALD), PEALD, atomic layer etching (ALE), PEALE, chemical vapor etching (CVE), PECVE, and/or the like. As shown, system 200 includes process chamber 201 that encloses various other components of system 200 and may contain, if used, radio frequency (RF) plasma. System 200 may include upper electrode 203 and substrate support 205, such as an electrostatic chuck (ESC), mechanical chuck, pedestal, or any other suitable substrate support. In some cases, substrate support 205 may include a fork and/or lift pins to hold and facilitate transfer of substrate 207. During operation, substrate 207 may be supported by or otherwise arranged on substrate support 205.

[0050] According to some aspects, upper electrode 203 may include or define a portion of a gas distribution assembly, such as a showerhead fluidically connected to junction point 209 of a gas distribution network. Upper electrode 203 may introduce and distribute one or more gases received from junction point 209 in at least process volume 211 defined between the gas distribution assembly and substrate 207. Hereinafter, it will be assumed that upper electrode 203 is a showerhead of the gas distribution assembly, and thus, the showerhead and the upper electrode may be referenced as showerhead 203. Junction point 209 may be at least one of (or an aggregation or assembly of) one or more conduits, valves, multiway conduit fittings, mixing bowls, charge plenums, manifolds, and/or the like. In some cases, junction point 209 may be configured to mix one or more precursor vapors received from at least one vapor delivery system (e.g., vapor delivery system 213) via one or more first conduits (or supply lines), such as first conduit 215, with one or more gases supplied via one or more second conduits (or supply lines), such as main gas supply line 217. In some cases, showerhead 203 may include a stem portion having a first end connected to a top surface of

process chamber 201 and a second end connected to showerhead 203, but embodiments are not limited thereto. For instance, showerhead 203 may form a top plate of process chamber 201, and as such, the stem portion may be arranged outside of interior cavity 219 of process chamber 201. In some implementations, showerhead 203 may have a generally cylindrical configuration that extends radially outwardly from the second end of the stem portion. A surface or faceplate of showerhead 203 that faces substrate 207 may include a plurality of gas distribution holes (or ports) through which one or more gases may flow, such as process gas, precursor vapors, purge gas, cleaning gas, etc. Alternately, showerhead 203 may include a conducting plate and the various gases may be introduced into process volume 211 in another manner.

[0051] Substrate support 205 may include a conductive baseplate that functions as a lower electrode. The conductive baseplate may support a heating plate, which may correspond to a ceramic multi-zone heating plate, but aspects are not limited thereto. A thermal resistance layer may be arranged between the heating plate and a substrate supporting surface of substrate support 205. In addition, substrate support 205 may include one or more coolant channels configured to flow coolant through substrate support 205.

[0052] In some aspects, system 200 may include RF generating system 221 configured to generate and output an RF voltage to one of the upper electrode of showerhead 203 and a lower electrode of substrate support 205. The other of the upper electrode and the lower electrode may be direct current (DC) grounded, alternating current (AC) grounded, or electrically floating. As shown, RF generating system 221 includes RF generator 223 configured to generate RF power that may be fed to the upper electrode or the lower electrode by matching and distribution network 225. The RF power may be utilized to generate plasma in process volume 211. In other examples, the plasma may be generated inductively or remotely. For instance, the plasma may be generated remotely by way of a remote plasma source and introduced to process volume 211 through a remote plasma source (RPS) valve fluidically connected to, for instance, junction point 209 or any other suitable input to showerhead 203 or process chamber 201.

[0053] One or more gas delivery systems, such as gas delivery systems 227_1, 227_2, . . . , and 227_M (where M is a positive integer greater than zero) may include one or more gas sources, such as gas sources 229_1, 229_2, . . . , and 229_N (where N is a positive integer greater than zero) of gas delivery system 227_1. For convenience, the one or more gas delivery systems and the one or more gas sources will be collectively or individually referred

to as gas delivery systems 227 and gas sources 229, respectively. Gas sources 229 are connected by respective valves 231_1, 231_2, . . . , and 231_N (hereinafter, collectively or individually referred to as valves 231) and corresponding mass flow controllers 233_1, 233_2, . . . , and 233_N (hereinafter, collectively or individually referred to as mass flow controllers 233) to manifold 235. In some implementations, at least one of gas delivery systems 227 may be fluidically connected to manifold 235 (such as gas delivery system 227_2) and/or at least one of gas delivery systems 227 may be fluidically connected to at least one manifold other than manifold 235 (such as gas delivery system 227_M). Outputs of the various manifolds (such as manifold 235) may be fluidically connected with junction point 209, which is fluidically connected with showerhead 203. Although gas delivery system 227_1 is shown with a particular configuration, gas may be delivered using any suitable gas delivery system(s). In some cases, one or more additional gas delivery systems 227_2, . . . , 227_M may fluidically communicate with junction point 209. In some cases, one of gas delivery systems 227 may include a cleaning gas source, such as an RPS gas source, that is fluidically connected with junction point 209.

[0054] According to some aspects, divert 237 may be fluidically interposed between vapor delivery system 213 and junction point 209. In some implementations, divert 237 may also be fluidically interposed between at least one of gas delivery systems 227, such as gas delivery system 227_M, and junction point 209. Divert 237 may include, for instance, one or more valves configured to selectively flow one or more received gases to junction point 209 (and, thereby, to a portion of main gas supply line 217 fluidically interposed between junction point 209 and process chamber 201) or to divert line 239, which may be fluidically connected with, for instance, an exhaust (e.g., a scrubbed exhaust) or other vacuum. In some cases, divert 237 may be configured to flow at least one received gas to both junction point 209 and divert line 239. Whatever the case, the operation of divert 237 may be controlled by at least one controller, such as system (or process) controller 241, based on one or more sequences of one or more instructions defining at least one process recipe of at least one semiconductor processing operation or stage thereof.

[0055] System 200 may also include pressure regulator 243 fluidically connected with divert line 239. In some cases, pressure regulator 243 may be connected inline with divert line 239, but implementations are not limited thereto. Pressure regulator 243 may be configured to control (or otherwise regulate) at least one flow condition (e.g., pressure, flow rate, mass flow rate, etc.) in at least one portion of divert line 239 based on pressure in main gas supply line

217. In some cases, the operation of pressure regulator 243 may be controlled by at least one controller, such as either or both of pressure controller 245 and system controller 241. To this end, one or more sensors (or transducers), such as sensors 247 and 249, may be fluidically connected with at least one of main gas supply line 217 and divert line 239 and configured to provide the at least one controller with one or more pieces of associated flow information (e.g., pressure, flow rate, mass flow rate, temperature, etc.) existing in a corresponding one of main gas supply line 217 and divert line 239. As will become more apparent below, the flow information may be utilized by the at least one controller to generate at least one control signal, such as a variable control signal, configured to control the operation of pressure regulator 243. Additional aspects of the gas delivery network of system 200 will be described in more detail in association with FIGS. 3–6.

[0056] System 200 may further include temperature controller 251, which may be communicatively connected with a plurality of thermal control elements arranged in association with one or more of process chamber 201, showerhead 203, and/or substrate support 205. In some cases, at least one of the thermal control elements may be arranged in association with at least one of junction point 209, main gas supply line 217, divert line 239, divert 237, and pressure regulator 243. In this manner, temperature controller 251 may be configured to control the plurality of thermal control elements to control a temperature of at least one of process chamber 201, showerhead 203, substrate support 205, substrate 207, junction point 209, main gas supply line 217, divert line 239, divert 237, and pressure regulator 243. In some cases, the thermal control elements may define one or more resistive heating elements, at least one of which may be included as part of a heating jacket forming a portion of (or connected to), for instance, junction point 209. It is noted that temperature controller 251 may communicate with fluid delivery system 253, which may be configured to control the flow of coolant to one or more components of process chamber 201, such as to at least one of showerhead 203 and substrate support 205. For example, fluid delivery system 253 may include a coolant pump and reservoir that are configured to regulate the flow of coolant through channels in substrate support 205, but aspects are not limited thereto. In some implementations, temperature controller 251 may be configured to operate fluid delivery system 253 to selectively flow the coolant to at least one of showerhead 203 and substrate support 205.

[0057] System controller 241 may be configured to operate system 200 by executing one or more sequences of one or more instructions defining at least one process recipe. As such,

system controller 241 may set various operational inputs for defining the at least one process recipe, such as power levels, ground settings, timing parameters, process gases, precursor vapors, purge gases, cleaning gases, flow rates, mass flow rates, distance of substrate 207 from showerhead 203, temperature of at least one of process chamber 201, showerhead 203, substrate support 205, substrate 207, junction point 209, main gas supply line 217, divert line 239, divert 237, and/or pressure regulator 243, shuttle speeds, mechanical movement of at least one of showerhead 203, substrate support 205, and substrate 207, pressure levels, etc. In some cases, system controller 241 may operate in conjunction with pressure controller 245 to control operation of pressure regulator 243, but implementations are not limited thereto. For instance, various features and/or functions described herein as being assigned to one of system controller 241 or pressure controller 245 may be fully or partially assumed by the other of system controller 241 and pressure controller 245. In some implementations, pressure controller 245, temperature controller 251, and/or system controller 241 may include, for instance, application-specific integrated circuits (ASIC), programmable logic devices (e.g., field-programmable gate arrays (FPGAs)), and/or the like, to control various components of system 200. In some cases, at least one of system controller 241 and pressure controller 245 may be or include a proportional-integral-derivative (PID) controller having a control loop mechanism employing feedback to control (e.g., continuously control) at least one processing condition of system 200, such as one or more flow conditions (e.g., pressure) within at least one portion of divert line 239 based on pressure within at least one portion of main gas supply line 217.

[0058] According to various aspects, gases (e.g., cleaning gases, process gases, carrier gases, precursor vapors, purge gases, etc.) may be caused to exit process chamber 201 via an exhaust gas port or outlet fluidically coupled to, for instance, vacuum pump 255. Vacuum pump 255 may be, in some instances, a one- or two-stage mechanical dry pump and/or a turbomolecular pump. As such, gas may be drawn out of process chamber 201 to maintain a suitably low pressure therein. To this end, a closed-loop flow restriction device 257, such as a throttle valve or a pendulum valve, may be controlled by way of, for example, system controller 241 to further ensure a suitably low pressure in process chamber 201. It is also noted that robot 259 may be used to deliver substrates (such as substrate 207) to, and remove substrates from, substrate support 205. For example, robot 259 may transfer substrate 207 between substrate support 205 and load lock 261.

[0059] In some implementations, system 200 may be implemented as a single-station or as

part of a multi-station tool. An example multi-station tool is described in more detail in association with FIG. 7.

Networks for Gas Delivery

[0060] FIG. 3 schematically illustrates a portion of a gas delivery network of the semiconductor processing system of FIG. 2 according to some aspects. FIG. 4 is a reference plot of pressure as a function of time at least for a main gas supply line and a divert line of the semiconductor processing system of FIG. 2 including the portion of the gas delivery network of FIG. 3 according to some aspects.

[0061] Precursor vapor 301, which may include vaporized precursor entrained in a carrier gas and/or a gaseous precursor, may enter portion 300 of the gas delivery network of system 200 (hereinafter, referred to as gas delivery network 300) through precursor inlet line 303. In some cases, precursor inlet line (or conduit) 303 may be fitted with a coupling that is fluidically connected with at least one precursor supply, such as an ampoule, storage vessel, facility line, etc. As such, precursor inlet valve 305 may control the introduction of precursor vapor 301 into gas delivery network 300. In some instances, precursor inlet valve 305 may be operated alternatively with purging inlet valve 307, which may be used to purge various components of system 200 of, for example, precursor residue and/or other actual (or potential) contaminants. Similar to precursor inlet valve 305, purging inlet valve 307 may be fitted with a coupling that is fluidically connected with one or more supplies of purge (or inert) gas 309, e.g., argon, helium, neon, nitrogen, and/or the like. For the purposes of this disclosure, an inert gas may be a gas that is non-reactive with precursor vapor 301 and/or counter-reactant(s) of an associated semiconductor process.

[0062] Precursor inlet valve 305 may be opened to allow precursor vapor 301 to flow into divert 311, which may be configured to control the flow rate of precursor vapor 301 and to selectively direct a flow of precursor vapor 301 to one of divert line (or conduit) 313 and portion 315a of process line (or conduit) 315 by way of junction point 317. Divert 311 may correspond with divert 237 in FIG. 2. In some implementations, gas delivery network 300 may include multiple precursor inlet lines and corresponding precursor inlet valves fluidically connected with divert 311 (and/or another similarly configured divert) to enable various chemistries of precursor vapors/gases to be supplied to process chamber 201.

[0063] Divert 311 may include one or more valves, such as divert valve 319 and outlet valve 323. Divert valve 319 may be configured to control the flow of precursor vapor 301 to one of junction point 317 (and, in association therewith, process chamber 201 via portion 315a of

process line 315) and divert line 313 under the control of, for instance, process controller 321. Process controller 321 may correspond with or may be communicatively coupled with system controller 241 in FIG. 2. Process line 315 and divert line 313 may respectively correspond with main gas supply line 217 and divert line 239 in FIG. 2. Junction point 317 may correspond with junction point 209 in FIG. 2. As previously described, divert line 313 may be fluidically connected with a vacuum, such as exhaust 325. In some cases, divert valve 319 may be a three-way control valve having an inlet fluidically connected with an outlet of precursor inlet valve 305, a first outlet fluidically connected with first portion 313a of divert line 313, and a second outlet fluidically connected with second portion 315a of process line 315 via outlet valve 323 and at least one conduit (or supply line), such as conduit 327. Outlet valve 323 may be fluidically interposed between divert valve 319 and junction point 317.

[0064] In some implementations, divert 311 may have one or more flow configurations, such as a first open configuration in which divert valve 319 is configured to fluidically connect a precursor delivery system (e.g., precursor delivery system 213) with exhaust 325 and outlet valve 323 is set in a closed configuration, a second open configuration in which divert valve 319 is configured to fluidically connect a precursor delivery system (e.g., precursor delivery system 213) with outlet valve 323 in a closed configuration, a third open configuration in which divert valve 319 is configured to fluidically connect a precursor delivery system (e.g., precursor delivery system 213) with junction point 317 and outlet valve 323 is set in an open configuration, and in some instances, a fourth open configuration in which divert valve 319 and outlet valve 323 are configured to fluidically connect a vapor delivery system (e.g., vapor delivery system 213) or a source of purge gas with both process chamber 201 and exhaust 325. It is noted that outlet valve 323 may also be under the control of, for example, process controller 321. As such, process controller 321 may be configured to alternate the flow of precursor vapor 301 and/or purge gas to divert line 313 and process line 315 according to one or more sequences of one or more instructions defining at least one stage of a process recipe, such as process recipe 329.

[0065] According to various implementations, divert line 313 may be a stainless-steel pipe (or other suitable conduit) having a diameter between about 0.125 inches and about 2 inches or any other suitable geometry and material may be used. In some cases, divert line 313 may be purged at the end of a semiconductor processing operation, e.g. divert line 313 may be vacuumed in parallel with process chamber 201 in order to avoid any residual build-up of precursor or other byproducts. In some cases, divert line 313 may be used to establish an

initial flow of precursor vapor 301 prior to flowing precursor vapor 301 to process chamber 201. For instance, when precursor vapor is typically introduced into a gas delivery network, a flow of the precursor vapor may undergo a stabilization period in which, for example, the flow rate reaches a steady state. For example, when precursor vapor is initially introduced, its flow rate may initially increase until it reaches a set point value. In some cases, the flow rate may experience a transitory period in which the flow rate oscillates between overshooting (or otherwise exceeding) and undershooting (or otherwise dropping below) a set point value before stabilizing. Given this period of oscillation, upper and lower process control limits may be set so that the flow rate (or some other process parameter) can be considered stabilized once the flow rate is maintained between these process control limits. The period of time for the flow rate (or some other process parameter) to reach a steady state or otherwise be considered stabilized is referred to, herein, as “a stabilization period.” To avoid inconsistent flow of precursor vapor 301 to process chamber 201 during a stabilization period of the flow, process controller 201 may be configured to cause, at least in part, divert valve 319 to be fluidically connected with exhaust 325, and as such, precursor vapor 301 to flow to exhaust 325. This may provide time for the flow of precursor vapor 301 to reach steady state prior to being flowed to process chamber 201. It is also contemplated that, during the stabilization period of the flow of precursor vapor 301, outlet valve 323 may be set in a closed configuration, and another gas (such as process gas 345) may be caused, at least in part, to flow to process chamber 201 via process line 315 and junction point 317.

[0066] As previously described, there can be a noticeable delay in the delivery of precursor vapor to a process chamber when the flow of the precursor vapor is switched from flowing to vacuum to flowing to the process chamber by, for example, a divert valve in a conventional gas delivery network. This delay may be caused, at least in part, by a mismatch in pressure between the divert line (and, thereby, the divert valve) and the main gas supply line when the switching operation is performed. For instance, if the divert line (and, thereby, the divert valve) is at a lower pressure than the main gas supply line, there can be a delay (such as a several second delay) during which time the pressure in at least the divert valve equalizes with the pressure in the main gas supply line (which may be flowing at least one other gas) to which the divert valve is fluidically connected. This equalization in pressure will allow the precursor vapor to flow into the main gas supply line. It is noted, however, that the time consumed for this pressure equalization to occur may not only increase the amount of time having to be allotted to an associated semiconductor processing operation, but may also

increase the amount of resources expended waiting for the flow of the precursor vapor process recipe 327 to restabilize in the main gas supply line. To eliminate, minimize, or at least reduce this delay, gas delivery network 300 may, in some implementations, include pressure regulator 243 fluidically connected with divert line 313 to control, e.g., actively control, the pressure (and/or some other flow condition) in divert line 313 based on the pressure (and/or some other flow condition) in process line 315 before, during, and/or after process controller 321 causes, at least in part, the flow of precursor vapor 301 to switch from flowing to exhaust 325 to flowing to process chamber 201 by way of junction point 317. In some cases, pressure regulator 243 may be controlled by pressure controller 245, which may receive control information (or signals) and/or pressure information (or signals) from at least one of process controller 321, first transducer 331 (e.g., a pressure transducer) fluidically connected with divert line 313, and second transducer 333 (e.g., a pressure transducer) fluidically connected with process line 315. First and second transducers 331 and 333 may respectively correspond with sensors 247 and 249 described in association with FIG. 2. It is also contemplated that one or more features and/or functions provided by pressure controller 245 may be assumed by process controller 321, or vice versa.

[0067] According to some embodiments, at least two among pressure regulator 243, pressure controller 245, and first transducer 331 may form portions of a same structure (or assembly) that is distinct from a structure including process controller 321. For instance, pressure regulator 243, pressure controller 245, and first transducer 331 may form pressure regulating device 335 having inlet 337 fluidically connected with portion 313a of divert line 313 and outlet 339 fluidically connected with portion 313b of divert line 313. In some cases, pressure regulator 243, pressure controller 245, and first transducer 331 may be supported in or by a same housing, but implementations are not limited thereto. For descriptive convenience, it will be assumed that pressure regulator 243, pressure controller 245, and first transducer 331 are supported in a same housing forming pressure regulating device 335.

[0068] As depicted in FIG. 3, first transducer 331 may be arranged upstream from pressure regulator 243, e.g., first transducer 331 may be fluidically interposed between pressure regulator 243 and divert valve 319. In some cases, first transducer 331 may be tapped into portion 313a of divert line 313 and, thereby, may not necessarily be fluidically interposed between pressure regulator 243 and divert valve 319, but nevertheless, considered upstream from pressure regulator 243. First transducer 331 may be or include a capacitance manometer configured to determine (e.g., measure) pressure (and, in some cases, vacuum) in

portion 313a of divert line 313, but embodiments are not limited thereto. For example, any other suitable sensor or combination of sensors may be utilized to determine pressure in portion 313a of divert line 313. Whatever the case, a flow of, for example, precursor vapor 301 may sequentially flow through (or by) inlet 337, pressure regulator 243, and outlet 339. To this end, pressure regulator 243 may be configured to control an upstream flow condition (e.g., upstream pressure), e.g., control the flow condition in portion 313a of divert line 313, but embodiments are not limited thereto. For example, pressure regulator 243 may be configured to control a downstream flow condition (e.g., downstream pressure), e.g., control the flow condition in portion 313b of divert line 313. In other cases, pressure regulator 243 may be configured to control both the upstream flow condition and the downstream flow condition. For descriptive convenience, it will be assumed that pressure regulator 243 is configured to control the upstream flow condition, e.g., pressure in portion 313a of divert line 313 fluidically interposed between the first outlet of divert valve 319 and inlet 337 of pressure regulating device 335.

[0069] Pressure regulator 243 may, in some instances, be or include a proportional control valve configured to adjust the volume of gas flowing through an orifice of inlet 337. For instance, pressure regulator 243 may include a proportional solenoid configured to adjust a volume of flowing gas, such as precursor vapor 301. Application of a voltage to the proportional solenoid may change the speed at which a spool of the proportional control valve shifts or a distance which the spool travels, thereby adjusting a volume of flowing gas responsive to the position of the spool. It is contemplated, however, that any other suitable control valve may be used. Whatever the case, pressure controller 245 may be configured to apply the voltage (or other control signal) to pressure regulator 243 to control the volume of flowing gas, and thereby, a pressure in portion 313a of divert line 313. As will become more apparent below, control over the pressure (and/or one or more other flow conditions) in portion 313a of divert line 313 based on the pressure (an/or one or more other flow conditions) in process line 315 may serve to equalize (or substantially equalize) the pressure in divert 311 with the pressure in process line 315 to allow the flow of precursor vapor 301 to more quickly flow into process line 315 when divert 311 is caused, at least in part, to switch the flow of precursor vapor 301 from exhaust 325 to process chamber 201. In some cases, control of the pressure in portion 313a of divert line 313 to equalize (or substantially equalize) with the pressure in process line 315 may cause the pressure in portion 313a of divert line 313 to increase to the pressure in process line 315, but implementations are not

limited thereto. It is also contemplated that pressure regulator 243 may be configured to equalize the pressure in portion 313a of divert line 313 with the pressure in process line 315 within a determined margin of error, such as within about ± 10 percent, e.g., within about ± 5 percent, for instance, within about ± 1 percent or even less.

[0070] According to some implementations, process controller 321 may be configured to receive first information from second transducer 333 corresponding to pressure in process line 315. The first information may be conveyed to process controller 321 in the form of an analog voltage signal, but embodiments are not limited thereto. Process controller 321 may be configured to generate first control information based on or using at least some of the first information. In some cases, process controller 321 may be configured to process (e.g., average) the first information over a determined duration and utilize the processed first information to generate the first control information, which may be in the form of an analog signal or a digital signal. It is also contemplated that the generation of the first control information may be based on second information received from at least one of pressure controller 245 and first transducer 331 corresponding to pressure in portion 313a of divert line 313. For instance, process controller 321 may be configured to process (e.g., average) the first information with the second information to generate the first control information. Similar to the first information, the second information may be conveyed to process controller 321 in the form of an analog voltage signal, but embodiments are not limited thereto. In some cases, process controller 321 may additionally and/or alternatively generate the first control information such that the first control information conveys the processed first information as a target pressure to be achieved and the second information as actual pressure in portion 313a of divert line 313 that is to be controlled to the target pressure. Process controller 321 may, in some implementations, utilize the second information in association with the first information to determine whether or not to control an operation of, for instance, divert 311 or some other component of gas delivery network 300, such as control valve 343 that is described later or one or more features of process chamber 201 in association with process recipe 329. For example, process controller 321 may compare the second information with the first information to determine whether or not to toggle at least one configuration of one or more of divert valve 319, outlet valve 323323, and control valve 343 between closed and open configurations, or vice versa.

[0071] Process controller 321 may be configured to transmit the first control information to pressure controller 245, which may be configured to generate a variable control signal based

on (or using) the first information. Pressure controller 245 may apply the variable control signal to pressure regulator 243 to control the pressure within portion 313a of divert line 313, and thereby, the pressure within divert 311, such as the pressure within divert valve 319. The variable control signal may, in some cases, be an analog control signal or a digital control signal. In some implementations, pressure controller 245 may receive the second information from first transducer 331 and generate (or modify) the variable control signal based on one or more of the first control information and the second information. For example, pressure controller 245 may be configured to utilize the first control information and the second information to generate a variable control signal at least partially defined by a function (e.g., a ramp function) that, when applied to pressure regulator 243, is configured to cause, at least in part, pressure regulator 243 to increase (e.g., ramp up) and equalize (or substantially equalize) the pressure in portion 313a of divert line 313 with the pressure in process line 315 within a determined margin of error. With respect to a ramp function, the second information may relate to an initial state and the first control information may relate to a target state that the ramp function increases to over time.

[0072] An example variable control signal that may be generated by pressure controller 245 is depicted in FIG. 4 as control signal 401. Plot lines 403 and 405 respectively illustrate the pressure in portion 313a of divert line 313 as a result of applying control signal 401 to pressure regulator 243 and a target pressure corresponding to the pressure in process line 315. In some cases, control signal 401 may include ramp portion 401r configured to linearly ramp the pressure in portion 313a of divert line 313 from pressure p1 (e.g., the pressure in portion 313a of divert line 313 when precursor vapor 301 is being flowed to exhaust 325) towards target pressure pt (e.g., the pressure in process line 315). For illustrative convenience, control signal 401 is shown offset from corresponding portions of plot lines 403 and 405 that would otherwise coincide with one another. For example, the portion of control signal 401 and plot line 403 prior to time t0 would coincide or substantially coincide with one another. Similarly, a majority of ramp portion 401r of control signal 401 would coincide or substantially coincide with a corresponding portion of plot line 403, as would corresponding portions of control signal 401 and plot line 405 from time t1 to at least time t2. Although ramp portion 401 is shown having a linear configuration, any other suitable function may be utilized, such as any suitable nonlinear function, piecewise function, etc. As can be appreciated from FIG. 4, utilization of pressure regulator 243 and control signal 401 may enable the pressure in portion 313a of divert line 313 (and, thereby, pressure in divert

311/divert valve 319) to more quickly stabilize at target pressure p_t (or between upper and lower process control pressure limits p_2 and p_3) than in the case of a conventional system conveyed via plot line 407 that lacks active pressure control of divert line 313. It is noted that an increase in pressure in a divert of a conventional system may increase based on transient pressure balancing with the pressure in a corresponding process line and an increase in the flow of precursor vapor from a vapor delivery system. This, in turn, may cause more variability in the pressure of the precursor vapor supply, which is shown by the more drastic overshooting and undershooting of plot line 407 relative to target pressure p_t . The decrease in time, in association with various implementations of gas delivery network 300, may effectively eliminate, minimize, or at least reduce the time from the point at which divert 311 is caused, at least in part, to switch the flow of precursor vapor 301 from exhaust 325 to process chamber 201 and the point at which the flow of precursor vapor 301 is capable of flowing into junction point 317 and, thereby, process line 315 from divert 311. Plot line 403 also demonstrates that the pressure in portion 313a of divert line 313 (and, thereby, the pressure in divert 311) may be more stably controlled (e.g., less overshooting and undershooting) than in a conventional system (conveyed via plot line 407) given that the source of the pressure change is controlled by pressure regulator 243 versus left to uncontrolled stabilization of conditions in one or more supply conduits that may be effected by various phenomena (e.g., gas pockets, surface tension, etc.) that typically cause, at least in part, pressure fluctuations around a target value.

[0073] As shown in FIG. 3, divert 311 is fluidically connected with junction point 317 via conduit 327. In some implementations, gas filter 341 (such as a vapor gas filter) may be fluidically connected between outlet valve 323 of divert 311 and junction point 317. In some cases, at least one other control valve (e.g., control valve 343) may be fluidically interposed between gas filter 341 and junction point 317. Control valve 343, when utilized, may be configured to, in an open configuration, control the flow of precursor vapor 301 into junction point 317 and, in a closed configuration, prevent backflow of gas from junction point 317 towards divert 311. In some cases, gas filter 341 may be configured to remove contaminants (e.g., particulate matter) from a flow of precursor vapor 301 prior to it being introduced into junction point 317. As such, gas filter 341 may include any suitable number of traps, filters, membranes, media, cyclones, catalytic materials, indicators, sensors, etc., to prevent or at least reduce the diffusion of actual or potential contaminants in the flow of precursor vapor 301 output from divert 311. It is also noted that selective configuration of outlet valve 323

and control valve 343 may be utilized to maintain (or substantially maintain) a pressure level (or pressure level range) within at least one portion of conduit 327. For example, prior to divert valve 319 being caused, at least in part, to switch a flow of one or more gases (e.g., inert gas) from process chamber 201 to exhaust 325, process controller 321 may be configured to sequentially toggle outlet valve 323 and control valve 343 into closed configurations to trap at least some of the gas(es) between outlet valve 323 and control valve 343 to maintain pressure in at least a portion of conduit 327. It is noted, however, that the maintenance of the pressure in the at least one portion of conduit 327 may be within a determined margin of error, e.g., within about ± 10 percent, such as within about ± 5 percent, for instance, within about ± 1 percent or even less.

[0074] According to some implementations, process controller 321 may utilize the second information (e.g., the pressure in portion 313a of divert line 313) received from at least one of pressure controller 245 and first transducer 331 to wait to switch divert valve 319 from flowing precursor vapor 301 to exhaust 325 to flowing precursor vapor 301 to process chamber 201 until the pressure in portion 313a of divert line 313 is at least equalized (or substantially equalized) with the pressure in process line 315. In some cases, process controller 321 may utilize the second information to wait to switch outlet valve 323 into an open configuration from a closed configuration until the pressure in portion 313a of divert line 313 is at least equalized (or substantially equalized) with the pressure in process line 315 and divert valve 319 is caused, at least in part, to be switched from flowing precursor vapor 301 to exhaust 325 to flowing precursor vapor 301 to process chamber 201.

[0075] As previously described in association with FIG. 2, junction point 317 may also be fluidically connected with one or more other sources of gas 345, such as process gas, via portion 315b of process line 315. In some implementations, the source of gas 345 may be at least one of gas delivery systems 227, which may be configured to control the flow of gas 345 into portion 315a of process line 315, and thereby, into junction point 317. Gas 345 from process line 315 may, in some cases, be mixed with precursor vapor 301 in junction point 317 and the combination of gases may be flowed to process chamber 201 via portion 315a of process line 315.

Example Processes

[0076] FIGS. 5 and 6 are flowcharts of processes for actively controlling the pressure of a portion of a divert line based on the pressure in a main gas supply line according to some aspects. For descriptive convenience, process 500 will be described as being performed by

process controller 321 and process 600 will be described as being performed by pressure controller 245. It should be recognized, however, that one or more of the steps in either of processes 500 and 600 may be performed by the other of process controller 321 and pressure controller 245. In some cases, pressure controller 245 may be omitted and process controller 321 may control pressure regulator 243. It is also noted that the steps of processes 500 and 600 may be performed in any suitable order and/or combined in any suitable manner.

[0077] According to some embodiments, prior to the flow of precursor vapor 301 to either of process chamber 201 and exhaust 325, substrate 207 may be introduced into load lock 261 of process chamber 201 and supported via substrate support 205. In some cases, the temperature of substrate 205 may be controlled via substrate support 205, temperature controller 251, and/or fluid delivery system 253. At some point before or after substrate support 205 starts regulating the temperature of substrate 207, process chamber 201 may be closed and purge gas 309 may be flowed into process chamber 201 via divert 311, junction point 317, and process line 315. In this state, divert valve 311 may be configured to fluidically connect purging inlet valve 307 (which may be in an open state) with process chamber 201. As such, outlet valve 323 and control valve 343 may also be in open configurations. At some point thereafter, purging gas inlet valve 307, outlet valve 323, and control valve 343 may be toggled into closed configurations such that the flow of purge gas 309 to process chamber 201 is discontinued and substrate 207 may be indexed.

[0078] After a determined amount of time, one or more gases (e.g., process gas 345) may be introduced into process chamber 201 via process line 315. It will be, hereinafter, assumed that the one or more gases are process gas 345. As such, the flow of process gas 345 may traverse junction point 317 on its way to being distributed in process volume 211 of process chamber 201 via showerhead 203. It is also noted that RF generator 223 may be activated to ignite plasma using process gas 345 distributed in process volume 211. While the plasma is being ignited and stabilized, one or more of processes 500 and 600 may be initiated.

[0079] At step 501, process controller 321 may cause, at least in part, precursor vapor 301 to flow from vapor delivery system 213 to exhaust 325 via divert 311 and divert line 313. In association therewith, precursor inlet valve 305 may be configured in an open configuration, and each of purging inlet valve 307 and outlet valve 323 may be configured in closed configurations. Control valve 343 may also be configured in a closed configuration to prevent the backflow of process gas 345 from junction point 317 towards divert 311 via conduit 327. This initial flow of precursor vapor 301 to exhaust 325 may be allowed to

stabilize for a determined period of time, and during this period, process controller 321 may receive, per step 503, one or more first signals from second transducer 333 corresponding to the pressure in process line 315 in association with the flow of process gas 345 to process chamber 201. In some cases, process controller 321 may also receive, per step 505, one or more second signals from first transducer 331 relating to the pressure in portion 313a of divert line 313 in association with the flow of precursor vapor 301 to exhaust 325. It is noted that First and second transducers 331 and 333 may be configured to transmit analog voltage signals to process controller 321 that relate to the respective pressures in portion 313a of divert line 313 and process line 315. These signals are also referred to, herein, as the first and second information. It is also generally noted that the stabilization of the initial flow of precursor vapor 301 to exhaust 325 and the stabilization of the plasma generated via RF generator 223 may be done in parallel to increase overall process throughput, but embodiments are not limited thereto. Aligning the stabilization periods for the initial flow of precursor vapor 301 and the plasma may, however, avoid unnecessary waste of precursors, process gases, process time, etc.

[0080] At some point prior to, during, or shortly after the stabilization of the initial flow of precursor vapor 301 to exhaust 325, pressure controller 241 may utilize one or more of the first and second information to generate, in step 507, first control information as previously described in association with one or more of FIGS. 2–4. This may include pressure controller 241 processing (averaging) at least one of the first and second information to generate the first control information. At step 509, process controller 321 may transmit the first control information to pressure controller 245, which may receive the first control information in association with step 601.

[0081] According to step 603, pressure controller 245 may receive one or more second signals from first transducer 331 corresponding to pressure in portion 313a of divert line 313 in association with the flow of precursor vapor 301 to exhaust 325. Utilizing the first control information and the one or more second signals, pressure controller 245 may generate (in step 605) a variable control signal as previously described in association with one or more of FIGS. 2–4. This may include generating a variable control signal at least partially defined by a ramp function that, when applied to pressure regulator 243, may cause pressure regulator 243 to linearly ramp the pressure in portion 313a of divert line 313 from pressure p_1 (e.g., the pressure in portion 313a of divert line 313 when precursor vapor 301 is being flowed to exhaust 325) towards target pressure p_t (e.g., the pressure in process line 315). At step 607,

pressure controller 245 may apply the variable control signal to pressure regulator 243 to control the pressure in portion 313a of divert line 313. In some implementations, pressure controller 245 may receive, as part of step 609, one or more updated second signals from first transducer 331 corresponding to the pressure in portion 313a of divert line 313 as the pressure is controlled to reach target pressure pt. Pressure controller 245 may utilize the updated second signals to further modify the variable control signal and/or transmit the updated second signals to process controller 321. It is noted that process controller 321 may utilize the updated second signals to further control one or more functions of, for example, gas delivery network 300.

[0082] For example, process controller 321 may utilize the updated second signals to determine that the pressure in portion 313a of divert line 313 (and, thereby, the pressure in divert valve 319) has been increased and sufficiently equalized with the pressure in process line 315 within a determined margin of error. As such, process controller 321 may cause, at least in part, divert valve 319 to switch from flowing precursor vapor 301 to exhaust 325 to flowing precursor vapor at least to outlet valve 323, which may be in a closed configuration. At some point thereafter or simultaneously therewith (or, in some cases, at some point therebefore), process controller 321 may cause, at least in part, outlet valve 323 to be configured in an open configuration, thereby allowing the flow of precursor vapor to flow through gas filter 341 and at least reach control valve 343. At some point thereafter or simultaneously therewith (or, in some cases, at some point therebefore), process controller 321 may cause, at least in part, control valve 343 to be configured in an open state to allow precursor vapor 301 to enter junction point 317 and mix with process gas 345. At least because the pressure in divert 311 and conduit 327 may be sufficiently equalized with the pressure in process line 315, once control valve 343 is opened, the flow of precursor vapor 301 may immediately (or substantially immediately) flow into junction point 317, and as such, be allowed to reach process chamber 201 more quickly than if the pressure portion 313a of divert line 313 had not been controlled. This may allow less time to be devoted to stabilizing a flow of the mixture of precursor vapor 301 and process gas 345 to process chamber 201 and, thereby, allow an associated stage of a semiconductor processing operation to be initiated more quickly. This may also waste less resources (e.g., precursor vapor, process gas, power, etc.). It is noted that showerhead 203 may receive and distribute the gas mixture in process volume 211 to allow the semiconductor processing operation (e.g., deposition, etching, etc.) to be completed.

[0083] After the semiconductor processing operation is complete, the respective flows of process gas 345 and precursor vapor 301 may be terminated, and the plasma may be extinguished. In some cases, a delay may exist between the time at which the respective flows of process gas 345 and precursor vapor 301 are terminated and the time at which the plasma is extinguished. This delay, however, may help burn off excess precursor vapor in process chamber 201. In some instances, this delay may be omitted. Thereafter, substrate 207 may be removed from process chamber 201 and the various lines (e.g., divert line 313, process line 315, and conduit 327) of gas delivery network 300 may be purged.

Multi-station Processing Tool

[0084] As previously mentioned, system 200 may be implemented as a single-station or as part of a multi-station tool. FIG. 7 schematically illustrates a multi-station processing tool according to some aspects.

[0085] In some implementations, multi-station processing tool 700 can include an inbound load lock 703 and an outbound load lock 705, either or both of which may include a plasma source and/or an ultraviolet (UV) source. Robot 707, at atmospheric pressure, is configured to move wafers from a cassette loaded through pod 709 into inbound load lock 703 via an atmospheric port 711. Substrate 207 is placed by robot 707 on pedestal 713 in inbound load lock 703, atmospheric port 711 is closed, and inbound load lock 703 is pumped down. In instances in which inbound load lock 703 includes a remote plasma source, substrate 207 may be exposed to a remote plasma treatment in inbound load lock 703 prior to being introduced into processing chamber 715. Further, substrate 207 may be heated in inbound load lock 703 to, for example, remove moisture and/or adsorbed gases. Next, chamber transport port 717 to processing chamber 715 is opened, and another robot 719 places substrate 207 into the reactor on a pedestal of a first station shown in the reactor for processing. While the implementation depicted in FIG. 7 includes load locks, it will be appreciated that, in some implementations, direct entry of substrate 207 into a processing station may be provided.

[0086] As seen in FIG. 7, processing chamber 715 includes four process stations, numbered 1 to 4. Each station has a pedestal, gas distributor, divert (e.g., divert 311), and pressure regulating device (e.g., pressure regulating device 335). It will be appreciated that, in some cases, each process station may have different or multiple purposes. For example, in some aspects, a process station may be switchable between a chemical vapor deposition (CVD) and PECVD process mode. In another example, deposition operations, e.g., PECVD operations,

may be performed in one station, while exposure to UV radiation for UV curing may be performed in another station. In some cases, deposition and UV curing may be performed in the same station. Further, although processing chamber 715 shown as including four stations, aspects are not limited thereto. For example, processing chamber 715 may have any suitable number of stations, such as five or more stations, or three or less stations.

[0087] As previously mentioned, multi-station processing tool 700 may include a wafer handling system (e.g., robot 719 including spider forks 701) for transferring and/or positioning wafers within processing chamber 715. In some aspects, the wafer handling system may transfer wafers between various process stations and/or between a process station and a load lock. It is contemplated, however, that any suitable wafer handling system may be employed, such as, for example, wafer carousels, other wafer handling robots, etc. Further, multi-station processing tool 700 may include (or otherwise be coupled to) a system controller 723 employed to control process conditions and hardware states of multi-station processing tool 700. System controller 723 may include one or more memory devices 725, one or more mass storage devices 727, and one or more processors 729. Each processor 729 may include a central processing unit (CPU) or computer, analog, and/or digital input/output connections, stepper motor controller boards, etc.

[0088] In some aspects, system controller 723 controls each of the activities of multi-station processing tool 700. For instance, system controller 723 may execute system control software 731 stored in mass storage device 727, loaded into memory device 725, and executed by processor 729. Alternatively, control logic may be hard coded in system controller 723. Application specific integrated circuits (ASIC), programmable logic devices (e.g., field-programmable gate arrays (FPGAs)) and/or the like may be used for these purposes. In the following discussion, wherever “software” or “code” is used, functionally comparable hard coded logic may be used in its place. System control software 731 may include instructions for controlling the timing, mixture of gases, gas flow rates, chamber and/or station pressure, chamber and/or station temperature, conduit temperature and/or pressure, wafer temperature, target power levels, RF power levels, substrate pedestal, chuck and/or susceptor position, and other parameters of a particular process performed by multi-station processing tool 700. System control software 731 may be configured in any suitable way. For example, various process tool component subroutines or control objects may be written to control operation of the process tool components used to carry out various process tool processes. System control software 731 may be coded in any suitable computer readable

programming language.

[0089] In some aspects, system control software 731 may include input/output control (IOC) sequencing instructions for controlling the various parameters described above. Other computer software and/or programs stored on mass storage device 727 and/or memory device 725 associated with system controller 723 may be employed in some aspects. Examples of programs or sections of programs for this purpose include a substrate positioning program, a process gas control program, a pressure control program, a heater control program, a cooler control program, and a plasma control program.

[0090] A substrate positioning program may include program code for process tool components that are used to load and orientate substrate 207 on pedestal 721 and to control the spacing between substrate 207 and other parts of multi-station processing tool 700.

[0091] A process gas control program may include code for controlling gas composition (e.g., silicon-containing gases, oxygen-containing gases, nitrogen-containing gases, dilution (or inert) gases, etc.), pressures, and flow rates, and optionally for flowing gas into one or more process stations prior to deposition to stabilize the pressure in the process station or at least one line or conduit. A pressure control program may include code for controlling the pressure in the process station by regulating, for example, a throttle valve in an exhaust system of the process station, a gas flow into the process station, and/or the like. In some cases, the pressure control program may include code for controlling the pressure in one or more conduits or lines and/or for controlling the pressure between the one or more lines. For instance, the pressure control program may control the operation of a pressure regulator (e.g., pressure regulator 243) to equalize (or substantially equalize) the pressure in a divert line with the pressure in a main gas supply line.

[0092] A heater control program may include code for controlling current to one or more heating units (e.g., a heating element incorporated as part of a pedestal and/or a showerhead, heating jacket, etc.) used to heat a pedestal (e.g., pedestal 721), a showerhead (e.g., showerhead 203) of processing chamber 715, a junction point (e.g., junction point 317) and/or conduit (e.g., divert line 313, process line 315, conduit 327) of a gas delivery network (e.g., gas delivery network 30), and/or the like, and thereby, to heat substrate 207 and/or one or more gases flowing from a source into the process chamber or to an exhaust. In addition or alternatively, the heater control program may control delivery of a heat transfer gas (such as helium) to a gas distributor, and, thereby, to substrate 207.

[0093] A cooling control program may include code for controlling a flow rate of conductive

cooling fluid through a cooling unit used to extract heat from a pedestal (e.g., pedestal 721) and/or a showerhead (e.g., showerhead 203) of processing chamber 715, and thereby, transfer such thermal energy to, for instance, a waste heat capturing, storage, recycling, and/or disposing system. The flow of the cooling fluid through the cooling unit may also extract heat from substrate 207.

[0094] A plasma control program may include code for setting RF power levels applied to the process electrodes in one or more process stations in accordance with various aspects.

[0095] A pressure control program may include code for maintaining pressure in a reaction chamber in accordance with various aspects.

[0096] In some aspects, a user interface may be provided in association with system controller 723. The user interface may include a display screen, graphical software displays of the apparatus and/or process conditions, and user input devices, such as pointing devices, keyboards, touch screens, microphones, etc.

[0097] In some aspects, parameters adjusted by system controller 723 may relate to process conditions. Non-limiting examples include process gas composition and flow rates, temperature, pressure, plasma conditions (such as RF bias power levels), pressure, temperature, etc. These parameters may be provided to the user in the form of a recipe, which may be entered utilizing the user interface.

[0098] Signals for monitoring the process may be provided by analog and/or digital input connections of system controller 723 from various process tool sensors. The signals for controlling the process may be output on analog and/or digital output connections of multi-station process tool 700. Non-limiting examples of process tool sensors that may be monitored include mass flow controllers, pressure sensors (such as manometers), thermocouples, etc. Appropriately programmed feedback and control algorithms may be used with data from the sensors to maintain process conditions.

[0099] System controller 723 may provide program instructions for implementing one or more of the above-described processes. The program instructions may control a variety of process parameters, such as direct current (DC) power level, RF bias power level, pressure, temperature, etc. The instructions may control the parameters to operate deposition of film stacks of a stress compensation layer according to various aspects.

[0100] System controller 723 will typically include one or more memory devices and one or more processors configured to execute the instructions so that the apparatus will perform a method in accordance with some aspects. In some instances, machine-readable media

containing instructions for controlling process operations in accordance with various aspects may be coupled to system controller 723.

[0101] In some aspects, system controller 723 may be part of a system, which may be part of at least one of the above-described examples. Such systems may include semiconductor processing equipment, including a processing tool or tools, a chamber or chambers, a platform or platforms for processing, and/or specific processing components (e.g., a wafer pedestal, a gas flow system, a thermal management system, etc.). The systems discussed above may be integrated with electronics for controlling their operation before, during, and/or after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. For instance, system controller 723, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), valve operation, light source control for radiative heating, pressure settings, vacuum settings, power settings, RF generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operational settings, wafer transfers into and out of a tool or chamber and other transfer tools and/or load locks connected to or interfaced with a specific system. In this manner, system controller 723 may be configured to control, among other systems, the various actuators and motors of a backside wafer processing system.

[0102] Broadly speaking, system controller 723 may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and/or the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to system controller 723 in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some aspects, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon oxide, surfaces, circuits, dies of a wafer, etc.

[0103] System controller 723, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the system, otherwise networked to the system, or a combination thereof. For example, system controller 723 may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g., a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It is to be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus, as described above, system controller 723 may be distributed, such as by including one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

[0104] Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and/or any other semiconductor processing system that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0105] As noted above, depending on the process step or steps to be performed by the tool, system controller 723 might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools,

tools located throughout a factory, a main computer, another controller, and/or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

[0106] Example Embodiments

[0107] Embodiment 1: An apparatus for semiconductor processing, the apparatus comprising: a junction point; a gas delivery system fluidically connected with the junction point via a first conduit, the gas delivery system being configured to supply at least one process gas to the junction point; a precursor delivery system fluidically connected with the junction point via a second conduit, the precursor delivery system being configured to supply at least one precursor to the junction point in a vapor and/or gaseous phase; a divert valve comprising: a first inlet fluidically connected with the precursor delivery system via a third conduit; a first outlet fluidically connected with the junction point via the second conduit; a second outlet fluidically connected with an exhaust via a fourth conduit; and a pressure regulator fluidically interposed between the second outlet and the exhaust, the pressure regulator being configured to control pressure in at least a portion of the fourth conduit based on pressure in the first conduit.

[0108] Embodiment 2: The apparatus of embodiment 1, wherein the portion of the fourth conduit is fluidically interposed between the divert valve and the pressure regulator.

[0109] Embodiment 3: The apparatus of either embodiment 1 or embodiment 2, wherein the control of the pressure in the portion of the fourth conduit is configured to cause, at least in part, the pressure in the portion of the fourth conduit to increase and equalize with the pressure in the first conduit within a determined margin of error.

[0110] Embodiment 4: The apparatus of any one of embodiments 1–3, further comprising: at least one controller operatively connected with the pressure regulator; and a first pressure transducer fluidically connected with the first conduit and communicatively coupled with the at least one controller, the first pressure transducer being configured to provide first information to the at least one controller corresponding to the pressure in the first conduit, wherein the at least one controller is configured to: receive the first information from the first pressure transducer; and control operation of the pressure regulator based on the first information.

[0111] Embodiment 5: The apparatus of embodiment 4, wherein the first pressure transducer is arranged in association with a portion of the first conduit fluidically interposed between the gas delivery system and the junction point.

[0112] Embodiment 6: The apparatus of either embodiment 4 or embodiment 5, wherein the at least one controller is configured to: convert the first information into a variable control signal; and apply the variable control signal to the pressure regulator.

[0113] Embodiment 7: The apparatus of embodiment 6, wherein the variable control signal is at least partially defined by a ramp function.

[0114] Embodiment 8: The apparatus of any one of embodiments 4–7, further comprising: a second pressure transducer fluidically connected with the fourth conduit and communicatively coupled with the at least one controller, the second pressure transducer being configured to provide second information to the at least one controller corresponding to the pressure in at least the portion of the fourth conduit, wherein the at least one controller is configured to: receive the second information from the second pressure transducer; and control operation of the pressure regulator based further on the second information.

[0115] Embodiment 9: The apparatus of embodiment 8, wherein the second pressure transducer is arranged in association with the portion of the fourth conduit.

[0116] Embodiment 10: The apparatus of any one of embodiments 4–9, wherein the at least one controller comprises a proportional-integral-derivative controller.

[0117] Embodiment 11: The apparatus of any one of embodiments 4–10, wherein: the at least one controller includes a pressure controller and a process controller; the pressure controller is operatively connected with the pressure regulator and configured to control the operation of the pressure regulator based on first control information; and the process controller is communicatively coupled with the pressure controller and the first pressure transducer, the process controller being configured to: receive the first information from the first pressure transducer; process the first information to generate the first control information; and transmit the first control information to the pressure controller.

[0118] Embodiment 12: The apparatus of embodiment 11, when directly or indirectly dependent from embodiment 8, wherein the pressure controller, the pressure regulator, and the second pressure transducer form portions of a same structure that is distinct from a structure comprising the process controller.

[0119] Embodiment 13: The apparatus of embodiment 12, wherein: the pressure regulator comprises a proportional control valve; and the second pressure transducer comprises a capacitance manometer.

[0120] Embodiment 14: The apparatus of any one of embodiments 11–13, wherein: the first information comprises an analog voltage signal; and the first control information comprises

either an analog signal or a digital signal.

[0121] Embodiment 15: The apparatus of any one of embodiments 11–14, when directly or indirectly dependent from embodiment 8, wherein: the pressure controller is configured to transmit the second information to the process controller; and the process controller is configured to generate the first control information based further on the second information.

[0122] Embodiment 16: The apparatus of any one of embodiments 11–15, wherein, as part of the generation of the first control information, the process controller is configured to determine an average of the first information over a determined period of time and utilize the average to generate the first control information.

[0123] Embodiment 17: The apparatus of any one of embodiments 11–16, wherein the process controller is operatively connected with the divert valve and configured to control operation of the divert valve according to a semiconductor process recipe.

[0124] Embodiment 18: The apparatus of embodiment 17, when directly or indirectly dependent from embodiment 3, wherein: as part of the semiconductor process recipe, the process controller is configured to cause, at least in part, the divert valve to toggle between a first open configuration and a second open configuration; in the first open configuration, the divert valve is configured to fluidically connect the precursor delivery system with the exhaust; in the second open configuration, the divert valve is configured to fluidically connect the precursor delivery system with the junction point; and the pressure in the portion of the fourth conduit is caused, at least in part, to be equalized with the pressure in the first conduit within the determined margin of error prior to the divert valve being toggled from the first open configuration to the second open configuration.

[0125] Embodiment 19: The apparatus of any one of embodiments 1–18, further comprising: at least one control valve fluidically connected with the second conduit and fluidically interposed between the divert valve and the junction point, wherein, in a closed configuration of the at least one control valve, a pressure in at least a portion of the second conduit is caused, at least in part, to be maintained at the pressure in the first conduit within a determined margin of error.

[0126] Embodiment 20: The apparatus of embodiment 19, when dependent from embodiment 18, wherein: the process controller is operatively coupled with the at least one control valve; as part of the semiconductor process recipe, the process controller is configured to cause, at least in part, the at least one control valve to toggle from the closed configuration to an open configuration; in the open configuration, the at least one control

valve is configured to fluidically connect the precursor delivery system with the junction point; in the closed configuration, the at least one control valve is configured to block a flow of the at least one precursor in the vapor and/or gaseous phase to junction point; and the pressure in the portion of the fourth conduit is caused, at least in part, to be equalized with the pressure in the first conduit within the determined margin of error and the divert valve is caused, at least in part, to be toggled from the first open configuration to the second open configuration prior to the at least one control valve being toggled from the closed configuration to the open configuration.

[0127] Embodiment 21: The apparatus of any one of embodiments 1–20, further comprising: a first inlet control valve fluidically interposed between the precursor delivery system and the first inlet of the divert valve; and a second inlet control valve fluidically interposed between a source of purge gas and the first inlet of the divert valve, wherein: the first inlet control valve is configured, when in a closed configuration, to block a flow of the at least one precursor in the vapor and/or gaseous phase to the divert valve; and the second inlet control valve is configured, when in an open configuration, to cause, at least in part, the purge gas to flow in at least one of the second conduit and the fourth conduit when the first inlet control valve is in the closed configuration and the divert valve is in at least one open configuration.

[0128] Embodiment 22: The apparatus of any one of embodiments 1–21, wherein: the divert valve comprises a three-way control valve; and the junction point comprises at least one of a gas mixing bowl, a charge plenum, and a multiway conduit fitting.

[0129] Embodiment 23: The apparatus of any one of embodiments 1–22, further comprising: a gas filter fluidically interposed between the divert valve and the junction point, the gas filter being configured to remove particulate matter from a flow of the at least one precursor in the vapor and/or gaseous phase prior to the flow being input to junction point.

[0130] Embodiment 24: The apparatus of embodiment 23, when directly or indirectly dependent from embodiment 19, wherein: the at least one control valve comprises a first control valve fluidically connected with the first outlet of the divert valve and a second control valve fluidically interposed between the first control valve and the junction point; and the gas filter is fluidically interposed between the first control valve and the second control valve.

[0131] Embodiment 25: The apparatus of embodiment 24, wherein: the at least one control valve further comprises a third control valve; and the third control valve is fluidically interposed between the first outlet of the divert valve and the first control valve.

[0132] Embodiment 26: The apparatus of any one of embodiments 1–25, further comprising: a process chamber; and a gas distributor fluidically connected with the junction point, the gas distributor being configured to distribute either or both of the at least one process gas and the at least one precursor in the vapor and/or gaseous phase in the process chamber in response to reception of a corresponding flow of the at least one process gas and/or the precursor in the vapor and/or gaseous phase.

[0133] Embodiment 27: The apparatus of embodiment 26, when directly or indirectly dependent from embodiment 8, further comprising: a radio frequency (“RF”) generator communicatively coupled with the process controller and configured to apply RF power to the gas distributor to generate plasma in the process chamber while the precursor in the vapor and/or gaseous phase is caused, at least in part, to be distributed in the process chamber.

Additional and/or Alternative Aspects

[0134] Unless otherwise specified, the illustrated aspects are to be understood as providing example features of varying detail of some aspects. Thus, unless otherwise specified, the features, components, modules, layers, films, regions, aspects, structures, etc. (hereinafter individually or collectively referred to as an “element” or “elements”), of the various illustrations may be otherwise combined, separated, interchanged, and/or rearranged without departing from the teachings of the disclosure.

[0135] The terminology used herein is for the purpose of describing some aspects and is not intended to be limiting. As used herein, the singular forms, “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It is to be understood that the phrases “for each <item> of the one or more <items>,” “each <item> of the one or more <items>,” and/or the like, if used herein, are inclusive of both a single-item group and multiple-item groups, i.e., the phrase “for . . . each” is used in the sense that it is used in programming languages to refer to each item of whatever population of items is referenced. For example, if the population of items referenced is a single item, then “each” would refer to only that single item (despite dictionary definitions of “each” frequently defining the term to refer to “every one of two or more things”) and would not imply that there must be at least two of those items. Similarly, the term “set” or “subset” should not be viewed, in itself, as necessarily encompassing a plurality of items—it is to be understood that a set or a subset can encompass only one member or multiple members (unless the context indicates otherwise). The terms “comprises,” “comprising,” “includes,” and/or “including,” when used in this specification, specify the presence of stated features, integers, steps,

operations, elements, components, and/or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. It is also noted that, as used herein, the terms “substantially,” “approximately,” “about,” and other similar terms, are used as terms of approximation and not as terms of degree, and, as such, are utilized to account for inherent deviations in measured, calculated, and/or provided values that would be recognized by one of ordinary skill in the art. Accordingly, the terms “substantially,” “approximately,” “about,” and the like as used herein, unless otherwise specified, means within 5% of a referenced value. For example, substantially perpendicular means within $\pm 5\%$ of parallel.

[0136] The use of cross-hatching and/or shading in the accompanying drawings is generally provided to clarify boundaries between adjacent elements. As such, neither the presence nor the absence of cross-hatching or shading conveys or indicates any preference or requirement for particular materials, material properties, dimensions, proportions, commonalities between illustrated elements, and/or any other characteristic, attribute, property, etc., of the elements, unless specified. Further, in the accompanying drawings, the size and relative sizes of elements may be exaggerated for clarity and/or descriptive purposes. As such, the sizes and relative sizes of the respective elements are not necessarily limited to the sizes and relative sizes shown in the drawings. When an aspect may be implemented differently, a specific process order may be performed differently from the described order. For example, two consecutively described processes may be performed substantially at the same time or performed in an order opposite to the described order.

[0137] When an element, such as a layer, is referred to as being “on,” “connected to,” or “coupled to” another element, it may be directly on, directly connected to, or directly coupled to the other element or at least one intervening element may be present. When, however, an element is referred to as being “directly on,” “directly connected to,” or “directly coupled to” another element, there are no intervening elements present. Other terms and/or phrases if used herein to describe a relationship between elements should be interpreted in a like fashion, such as “between” versus “directly between,” “adjacent” versus “directly adjacent,” “on” versus “directly on,” etc. Further, the term “connected” may refer to physical, electrical, and/or fluid connection. To this end, for the purposes of this disclosure, the phrase “fluidically connected” is used with respect to volumes, plenums, holes, etc., that may be connected to one another, either directly or via one or more intervening components or volumes, to form a fluidic connection, similar to how the phrase “electrically connected” is

used with respect to components that are connected to form an electric connection. The phrase “fluidically interposed,” if used, may be used to refer to a component, volume, plenum, hole, etc., that is fluidically connected with at least two other components, volumes, plenums, holes, etc., such that fluid flowing from one of those other components, volumes, plenums, holes etc., to the other or another of those components, volumes, plenums, holes, etc., would first flow through the “fluidically interposed” component before reaching that other or another of those components, volumes, plenums, holes, etc.. For example, if a pump is fluidically interposed between a reservoir and an outlet, fluid flowing from the reservoir to the outlet would first flow through the pump before reaching the outlet. The phrase “fluidically adjacent,” if used, refers to placement of a fluidic element relative to another fluidic element such that no potential structures fluidically are interposed between the two elements that might potentially interrupt fluid flow between the two fluidic elements. For example, in a flow path having a first valve, a second valve, and a third valve arranged sequentially therealong, the first valve would be fluidically adjacent to the second valve, the second valve fluidically adjacent to both the first and third valves, and the third valve fluidically adjacent to the second valve.

[0138] For the purposes of this disclosure, “at least one of X, Y, . . . , and Z” and “at least one selected from the group consisting of X, Y, . . . , and Z” may be construed as X only, Y only, . . . , Z only, or any combination of two or more of X, Y, . . . , and Z, such as, for instance, XYZ, XYY, YZ, and ZZ. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0139] Although the terms “first,” “second,” “third,” etc., may be used herein to describe various elements, these elements should not be limited by these terms. These terms are used to distinguish one element from another element. Thus, a first element discussed below could be termed a second element without departing from the teachings of the disclosure. To this end, use of such identifiers, e.g., “a first element,” should not be read as suggesting, implicitly or inherently, that there is necessarily another instance, e.g., “a second element.” Further, the use, if any, of ordinal indicators, such as (a), (b), (c), . . . , or (1), (2), (3), . . . , or the like, in this disclosure and accompanying claims, is to be understood as not conveying any particular order or sequence, except to the extent that such an order or sequence is explicitly indicated. For example, if there are three steps labeled (i), (ii), and (iii), it is to be understood that these steps may be performed in any order (or even concurrently, if not otherwise contraindicated), unless indicated otherwise. For example, if step (ii) involves the

handling of an element that is created in step (i), then step (ii) may be viewed as happening at some point after step (i). In a similar manner, if step (i) involves the handling of an element that is created in step (ii), the reverse is to be understood.

[0140] Spatially relative terms, such as “beneath,” “below,” “under,” “lower,” “above,” “upper,” “over,” “higher,” “side” (e.g., as in “sidewall”), and the like, may be used herein for descriptive purposes, and, thereby, to describe one element’s spatial relationship to at least one other element as illustrated in the drawings. Spatially relative terms are intended to encompass different orientations of an apparatus in use, operation, and/or manufacture in addition to the orientation depicted in the drawings. For example, if the apparatus in the drawings is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” or “over” the other elements or features. Thus, the term “below” can encompass both an orientation of above and below. Furthermore, the apparatus may be otherwise oriented (e.g., rotated 90 degrees or at other orientations), and, as such, the spatially relative descriptors used herein interpreted accordingly.

[0141] The term “between,” as used herein and when used with a range of values, is to be understood, unless otherwise indicated, as being inclusive of the start and end values of that range. For example, between 1 and 5 is to be understood as inclusive of the numbers 1, 2, 3, 4, and 5, not just the numbers 2, 3, and 4. Moreover, although specific examples, values, ranges, etc., are provided herein, other examples, values, ranges, etc. that are not expressly listed are to be considered as falling within the scope of the disclosure, such as in the case of using similar ratios, relationships, etc., as discussed above.

[0142] As used herein, the phrase “operatively connected” is to be understood as referring to a state in which two components and/or systems are connected, either directly or indirectly, such that, for example, at least one component or system can control the other. For instance, a controller may be described as being operatively connected with (or to) a resistive heating unit, which is inclusive of the controller being connected with a sub-controller of the resistive heating unit that is electrically connected with a relay that is configured to controllably connect or disconnect the resistive heating unit with a power source that is capable of providing an amount of power that is able to power the resistive heating unit so as to generate a desired degree of heating. The controller itself likely will not supply such power directly to the resistive heating unit due to the current(s) involved, but it is to be understood that the controller is nonetheless operatively connected with the resistive heating unit.

[0143] As used herein, the singular forms, “a,” “an,” and “the” are intended to include the

plural forms as well, unless the context clearly indicates otherwise. It is also to be understood that the phrases “for each <item> of the one or more <items>,” “each <item> of the one or more <items>,” and/or the like, if used herein, are inclusive of both a single-item group and multiple-item groups, i.e., the phrase “for . . . each” is used in the sense that it is used in programming languages to refer to each item of whatever population of items is referenced. For example, if the population of items referenced is a single item, then “each” would refer to only that single item (despite dictionary definitions of “each” frequently defining the term to refer to “every one of two or more things”) and would not imply that there must be at least two of those items. Similarly, the term “set” or “subset” should not be viewed, in itself, as necessarily encompassing a plurality of items—it is to be understood that a set or a subset can encompass only one member or multiple members (unless the context indicates otherwise). In addition, the terms “comprises,” “comprising,” “includes,” and/or “including,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0144] Various aspects are described herein with reference to sectional views, isometric views, perspective views, plan views, and/or exploded illustrations that are schematic depictions of idealized aspects and/or intermediate structures. As such, variations from the shapes of the illustrations as a result of, for example, manufacturing techniques and/or tolerances, are to be expected. Thus, aspects disclosed herein should not be construed as limited to the particular illustrated shapes of regions, but are to include deviations in shapes that result from, for instance, manufacturing. To this end, regions illustrated in the drawings may be schematic in nature and shapes of these regions may not reflect the actual shapes of regions of a device, and, as such, are not intended to be limiting.

[0145] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure is a part. Terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and are not to be interpreted in an idealized or overly formal sense, unless expressly so defined herein.

[0146] As customary in the field, some aspects are described and illustrated in the accompanying drawings in terms of functional blocks, units, and/or modules. Those skilled

in the art will appreciate that these blocks, units, and/or modules are physically implemented by electronic (or optical) circuits, such as logic circuits, discrete components, microprocessors, hard-wired circuits, memory elements, wiring connections, and the like, which may be formed using semiconductor-based fabrication techniques or other manufacturing technologies. In the case of the blocks, units, and/or modules being implemented by microprocessors or other similar hardware, they may be programmed and controlled using software (e.g., microcode) to perform various functions discussed herein and may optionally be driven by firmware and/or software. It is also contemplated that each block, unit, and/or module may be implemented by dedicated hardware, or as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. Also, each block, unit, and/or module of some aspects may be physically separated into two or more interacting and discrete blocks, units, and/or modules without departing from the inventive concepts. Further, the blocks, units, and/or modules of some aspects may be physically combined into more complex blocks, units, and/or modules without departing from the teachings of the disclosure.

[0147] Although the foregoing aspects have been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. It should be noted that there are many alternative ways of implementing the processes, systems, and apparatuses of the disclosed aspects. Accordingly, aspects are to be considered as illustrative and not as restrictive, and aspects are not to be limited to the details given herein.

CLAIMS

What is claimed is:

1. An apparatus for semiconductor processing, the apparatus comprising:
 - a junction point;
 - a gas delivery system fluidically connected with the junction point via a first conduit, the gas delivery system being configured to supply at least one process gas to the junction point;
 - a precursor delivery system fluidically connected with the junction point via a second conduit, the precursor delivery system being configured to supply at least one precursor to the junction point in a vapor and/or gaseous phase;
 - a divert valve comprising:
 - a first inlet fluidically connected with the precursor delivery system via a third conduit;
 - a first outlet fluidically connected with the junction point via the second conduit; and
 - a second outlet fluidically connected with an exhaust via a fourth conduit; and
 - a pressure regulator fluidically interposed between the second outlet and the exhaust, the pressure regulator being configured to control pressure in at least a portion of the fourth conduit based on pressure in the first conduit.
2. The apparatus of claim 1, wherein the portion of the fourth conduit is fluidically interposed between the divert valve and the pressure regulator.
3. The apparatus of claim 1, wherein the control of the pressure in the portion of the fourth conduit is configured to cause, at least in part, the pressure in the portion of the fourth conduit to increase and equalize with the pressure in the first conduit within a determined margin of error.
4. The apparatus of claim 1, further comprising:
 - at least one controller operatively connected with the pressure regulator; and
 - a first pressure transducer fluidically connected with the first conduit and communicatively coupled with the at least one controller, the first pressure transducer being configured to provide first information to the at least one controller corresponding to the

pressure in the first conduit, wherein the at least one controller is configured to:

receive the first information from the first pressure transducer; and
control operation of the pressure regulator based on the first information.

5. The apparatus of claim 4, wherein the first pressure transducer is arranged in association with a portion of the first conduit fluidically interposed between the gas delivery system and the junction point.

6. The apparatus of claim 4, wherein:
the at least one controller includes a pressure controller and a process controller;
the pressure controller is operatively connected with the pressure regulator and configured to control the operation of the pressure regulator based on a first control information; and
the process controller is communicatively coupled with the pressure controller and the first pressure transducer, the process controller being configured to:

receive the first information from the first pressure transducer;
process the first information to generate the first control information; and
transmit the first control information to the pressure controller.

7. The apparatus of claim 6, wherein the process controller is operatively connected with the divert valve and configured to control operation of the divert valve according to a semiconductor process recipe.

8. The apparatus of claim 7, wherein:
as part of the semiconductor process recipe, the process controller is configured to cause, at least in part, the divert valve to toggle between a first open configuration and a second open configuration;
in the first open configuration, the divert valve is configured to fluidically connect the precursor delivery system with the exhaust;
in the second open configuration, the divert valve is configured to fluidically connect the precursor delivery system with the junction point; and
the pressure in the portion of the fourth conduit is caused, at least in part, to be equalized with the pressure in the first conduit within a determined margin of error prior to

the divert valve being toggled from the first open configuration to the second open configuration.

9. The apparatus of claim 1, further comprising:

a first inlet control valve fluidically interposed between the precursor delivery system and the first inlet of the divert valve; and

a second inlet control valve fluidically interposed between a source of purge gas and the first inlet of the divert valve, wherein:

the first inlet control valve is configured, when in a closed configuration, to block a flow of the at least one precursor in the vapor and/or gaseous phase to the divert valve; and

the second inlet control valve is configured, when in an open configuration, to cause, at least in part, the purge gas to flow in at least one of the second conduit and the fourth conduit when the first inlet control valve is in the closed configuration and the divert valve is in at least one open configuration.

10. The apparatus of claim 1, wherein:

the divert valve comprises a three-way control valve; and

the junction point comprises at least one of a gas mixing bowl, a charge plenum, and a multiway conduit fitting.

11. The apparatus of claim 1, further comprising:

a process chamber; and

a gas distributor fluidically connected with the junction point, the gas distributor being configured to distribute either or both of the at least one process gas and the at least one precursor in the vapor and/or gaseous phase in the process chamber in response to reception of a corresponding flow of the at least one process gas and/or the precursor in the vapor and/or gaseous phase.