lines and/or in downstream gas distribution devices, which may cause additional substrate defects.

SUMMARY

[0008] A gas delivery system for a substrate processing system includes a first valve including an inlet and an outlet. The inlet of the first valve is in fluid communication with a first gas source. A second valve includes a first inlet, a second inlet and an outlet. The first inlet of the second valve is in fluid communication with ~~an~~ the outlet of the first valve and the second inlet is in fluid communication with a second gas source. A third valve includes an inlet and an outlet. The inlet of the third valve is in fluid communication with a third gas source. A connector includes a first gas channel and a cylinder defining a second gas channel having a first end and a second end. The cylinder is at least partially disposed within the first gas channel such that the cylinder and the first gas channel collectively define a flow channel between an outer surface of the cylinder and an inner surface of the first gas channel. The flow channel is in fluid communication with the outlet of the third valve and the first end of the second gas channel. A third gas channel is in fluid communication with the second end of the second gas channel, with the outlet of the second valve and with a gas distribution device of a processing chamber.

[0009] In other features, the first gas source includes a purge gas source. The second gas source includes a precursor gas source. A fourth valve includes an inlet and an outlet. The inlet of the fourth valve is in fluid communication with a fourth gas source. The outlet of the fourth valve is in fluid communication with the flow channel. The fourth

[0026] FIG. 6 is a schematic diagram of yet another example gas delivery system according to the present disclosure;

[0027] FIG. 7 illustrates timing of valves for an idealized gas delivery system;

[0028] FIG. 8 illustrates timing of valves for the gas delivery system of FIG. 4 according to the present disclosure;

[0029] FIG. 9 illustrates timing of valves for the gas delivery system of FIG. 6 according to the present disclosure; and

[0030] FIG. 10 is a flowchart illustrating an example of a method for supplying gas according to the present disclosure.

[0031] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

[0032] In some examples, the gas delivery systems and methods according to the present disclosure increase separation of a first reactant gas relative to a second reactant gas in gas lines of a substrate processing system to reduce substrate defects. In some examples, continuous flow of purge gas may be supplied to an inlet of a downstream connector where the second gas is introduced.

[0033] Spatial separation of the reactant gases in the gas lines ~~supplying~~ of the substrate processing system helps to reduce substrate defects. The spatial separation overcomes problems associated with temporal-only separation. By providing continuous purge gas flow to the inlet of the downstream connector and situating a valve supplying the second reactant gas remotely relative to the first reactant gas,

radially outwardly from an opposite end of the stem portion at a location that is spaced from the top surface of the processing chamber. A substrate-facing surface or faceplate of the base portion of the showerhead includes a plurality of holes through which process gas or purge gas flows. Alternately, the upper electrode 4 may include a conducting plate and the process gases may be introduced in another manner.

[0037] The ESC 6 includes a conductive baseplate 10 that acts as a lower electrode. The conductive baseplate 10 supports a heating plate 12, which may correspond to a ceramic multi-zone heating plate. A thermal resistance layer 14 may be arranged between the heating plate 12 and the baseplate 10. The baseplate 10 may include one or more coolant channels 16 for flowing coolant through the baseplate 10.

[0038] An RF generating system 20 generates and outputs an RF voltage to one of the upper electrode 4 and the lower electrode (e.g., the baseplate 10 of the ESC 6). The other one of the upper electrode 4 and the baseplate 10 may be DC grounded, AC grounded or floating. For example only, the RF generating system 20 may include an RF generator 22 that generates RF power that is fed by a matching and distribution network 24 to the upper electrode 4 or the baseplate 10. In other examples, the plasma may be generated inductively or remotely.

[0039] One or more gas delivery systems 30-1, 30-2, ..., and 30-M (collectively gas delivery systems 30) include one or more gas sources 32-1, 32-2,..., and 32-N (collectively gas sources 32), where M and N ~~is an~~ are integers greater than zero. The gas sources 32 are connected by valves 34-1, 34-2, ..., and 34-N (collectively valves 34) and mass flow controllers 36-1, 36-2, ..., and 36-N (collectively mass flow controllers 36) to a manifold 40. An output of the manifold 40 is fed to a gas separation system 41. While a

specific gas delivery system 30-1 is shown, gas may be delivered using any suitable gas delivery systems. One or more additional gas delivery systems 30-2, ..., and 30-M fluidly communicate with the gas separation system 41. A cleaning gas source 43 such as remote plasma clean (RPC) gas may also fluidly communicate with the gas separation system 41.

[0040] A temperature controller 42 may be connected to a plurality of thermal control elements (TCEs) 44 arranged in the heating plate 12. The temperature controller 42 may be used to control the plurality of TCEs 44 to control a temperature of the ESC 6 and the substrate 8. The temperature controller 42 may communicate with a coolant assembly 46 to control coolant flow through the channels 16. For example, the coolant assembly 46 may include a coolant pump and reservoir. The temperature controller 42 operates the coolant assembly 46 to selectively flow the coolant through the channels 16 to cool the ESC 6.

[0041] A valve 50 and pump 52 may be used to evacuate reactants from the processing chamber 2. A system controller 60 may be used to control components of the substrate processing system ~~10~~. A robot 70 may be used to deliver substrates onto, and remove substrates from, the ESC ~~106~~. For example, the robot 70 may transfer substrates between the ESC 6 and a load lock 72.

[0042] Referring now to FIG. 2, an example of the gas separation system 41 is shown to include a valve assembly 74 including a plurality of valves 76, 78, 80 and 82 connected by gas lines 83. An inlet of the valve 76 is connected to a purge gas source and an outlet of the valve 76 is connected to an inlet of the valve 78. Another inlet of the valve 78 is connected to a reactant gas such as an oxidizing gas source. An outlet

of the valve 78 is connected to an inlet of the valve 80. Another input of the valve 80 is connected to a reactant gas such as a precursor gas source.

[0043] An outlet of the valve 80 is connected to an elbow connector 84, which is connected to an outlet of a valve 86 and to the processing chamber. An inlet of the valve 86 is connected to a cleaning gas such as remote plasma clean (RPC) gas source. The valve 82 has an inlet connected to the precursor gas and an outlet.

[0044] During operation, the precursor gas may optionally be diverted using the valves 80 (connection from precursor gas inlet to outlet is closed) and 82 (opened) for a predetermined period. After diversion, the precursor gas is supplied to the processing chamber for a predetermined period using valves 80 (connection from precursor gas inlet to outlet is open) and 82 (closed) and then the supply of precursor gas is terminated. Purge gas is supplied to the processing chamber using valves 76, 78 and 80 and then terminated. Oxidizing gas is supplied to the processing chamber using valves 78 and 80. As can be appreciated, the precursor gas is supplied to the processing chamber using some of the same gas lines 83 and valves as the oxidizing gas.

[0045] Referring now to FIG. 3, operation of the valves of FIG. 2 is shown. Prior to a dose stage, purge gas may initially be supplied and diverted using the valves 80 and 82. After a predetermined period, the valves 80 and 82 are arranged to supply precursor gas to the processing chamber via the elbow connector 84 (dose stage). At the end of the dose stage, the valve 80 stops supplying precursor gas and is positioned to supply purge gas. During a burst purge stage, the purge gas is supplied via valves 76, 78, 80 and the elbow connector 84 to the processing chamber. At the end of the burst purge

stage, the valve 76 is closed. An oxidizing gas is supplied to the processing chamber during dose purge, RF and RF purge stages using the valves 78, 80 and the elbow connector 84.

[0046] The precursor gas and ~~oxidant~~ oxidizing gas are both supplied using the same group of valves and gas lines but are separated temporally. Temporal separation relies on large flow rates and sufficient time to fully clean out gas lines 83 between precursor gas flow and ~~oxidant~~ oxidizing gas flow. Either a sticky precursor or an insufficient amount of time allotted may result in defect formation due to reactions in the gas channels. In addition, high flow rates and switching between oxidizer, purge gas and precursor gas can introduce pressure transients in the gas channels and gas distribution devices.

[0047] Referring now to FIG. 4, a gas separation system 87 includes a valve assembly 88 including a plurality of valves 90, 92, 94, and 96 and gas lines 83. An inlet of the valve 90 is connected to a purge gas source and an outlet of the valve 90 is connected to an inlet of the valve 92. In some examples, the purge gas includes helium, argon or another inert gas. An outlet of the valve 92 is connected to an inlet of the valve 94. Another ~~input~~ inlet of the valve 94 is connected to a reactant gas such as precursor gas.

[0048] An outlet of the valve 94 is connected to an elbow connector 100, which is connected to an outlet of a valve 98 and to the processing chamber. An inlet of the valve 98 is connected to a process gas such as a remote plasma clean (RPC) source. The valve 96 has an inlet connected to the precursor gas and an outlet.

[0049] One or more valves 102A and 102B (collectively valve 102) are used to supply a reactant gas such as an oxidizing gas to an inlet 104 of the elbow connector 100. In

some examples, the valve 102 is arranged a distance between 10" and 40" from the inlet of the elbow connector 100.

[0050] Purge gas may also be continuously supplied to the inlet 104 of the elbow connector 100 or selectively supplied to the inlet 104 (during supply of oxidizing gas or at times other than during supply of oxidizing gas). A "T"-shaped fluid connector 105 has a first leg fluidly connected to the elbow connector 100, a second leg fluidly connected to the outlet of the valve 94 and a third leg fluidly connected to the processing chamber. In some examples, the "T"-shaped fluid connector 105 may be made of ceramic.

[0051] Referring now to FIG. 5, an example of the elbow connector 100 includes a first connector 122 connected to a valve assembly 120 and second connector 124. Additional details relating to the elbow connector 100 may be found in commonly-assigned U.S. Provisional Application No. 62/084,856, filed on November 26, 2014 and entitled "REMOTE PLASMA CLEAN ELBOW CONNECTOR WITH PURGING TO REDUCE ON-WAFER PARTICLES" and U.S. Patent Application No. ~~xx/xxx,xxx~~ 14/805,807, filed on ~~Month, xx~~July 22, 2015 and entitled "VALVE MANIFOLD DEADLEG ELIMINATION VIA REENTRANT FLOW PATH" (Attorney Docket No. 3585-2US), both of which are hereby incorporated by reference in their entirety.

[0052] The first connector 122 includes a first body 130 defining a first gas channel 132 including an inlet 133 and an outlet 134. The second connector 124 includes a second body 136 defining a second gas channel 138 including an inlet 139 and an outlet 140. The outlet 134 of the first gas channel 132 is connected to the inlet 139 of

temperature is maintained at a predetermined temperature above approximately ~65 °C, although the temperature will vary depending on the type of gas that is used and its condensation temperature.

[0056] Referring now to FIG. 6, another gas separation system 200 includes the valve assembly 88 described above. A valve 204 is arranged closer to the inlet 104 of the elbow connector 100. In some examples, the valve 204 is arranged a distance less than 10" from the inlet of the elbow connector 100. In other examples, the distance is less than or equal to 5", 2.5" or 1".

[0057] Referring now to FIGs. 7-9, various timing diagrams for valve sequencing and timing are shown. In FIG. 7, idealized valve sequencing and timing is shown. Ideally, the precursor gas flow ends at the same time as the oxidant gas flow begins and there is no overlap. In FIG. 8, operation of the valves in FIG. 4 is shown. There is less overlap ~~that~~ than that experienced in FIG. 2 between precursor and oxidizer due to line charge time. In FIG. 9, operation of the valves in FIG. 6 is shown. There may be some overlap in the "~~"~~T"-shaped fluid connector 105.

[0058] Referring now to FIG. 10, an example of a method 300 for operating the gas delivery system described above is shown. At 304, the method determines whether cleaning using remote plasma clean (RPC) gas or another cleaning gas should be performed. If true, the substrates are removed from the processing chamber and cleaning gas or RPC gas is supplied for a predetermined clean period.

[0059] If 304 is false, control determines whether an ALD process needs to be performed. If 306 is true, substrates are loaded into the processing chamber at 310. Additionally, a first reactant gas such as precursor gas is optionally supplied and