

VALVE APPARATUSES AND RELATED METHODS FOR REACTIVE PROCESS GAS ISOLATION AND FACILITATING PURGE DURING ISOLATION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of and priority to U.S. Serial No. 63/347,740, filed June 1, 2022, the entire content of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This application relates generally to isolation valves used in semiconductor processing. In particular, this application relates to multi-position isolation valves and related methods of use for preventing the degradation of the valve sealing element and enabling the remote plasma source and valve body to be purged simultaneously with semiconductor fabrication processes.

BACKGROUND

[0003] In order to reduce or prevent damage to the wafer and process chamber that can be caused by exposure to chemically corrosive plasmas, many semiconductor processing systems use a remote plasma source ("RPS") to generate a plasma outside the process chamber and then deliver activated gasses (e.g., reactive species, reactive gas) produced by the plasma to the process chamber for processing a wafer or substrate. It can be desirable to install an isolation valve in the aperture or conduit connecting an outlet of the RPS to an inlet of the process chamber. Such a valve can be used to isolate the RPS from the process chamber during deposition operations to prevent, for example, gasses from the process chamber from making their way up into the RPS and condensing or depositing a film on the RPS chamber walls. However, limitations of conventional valves have largely made their use impractical for this application.

[0004] Conventional valves that have been considered for use in semiconductor processing systems typically utilize a gate valve or a bellows-sealed poppet isolation valve.

[0005] Conventional gate valves typically are shorter in the direction of the gas flow than their poppet valve counterparts, but can be more susceptible to thermal issues. Further, gate

valves typically have a large internal wetted surface area that is exposed to the process gas when the valve is open.

[0006] A conventional bellows-sealed poppet isolation valve has a mechanically- or pneumatically-actuated piston for extending and retracting a bellows and nosepiece to close and open a gas flow path through the valve body. Such valves often have a valve body arranged in a side port configuration in which the valve opening connected to the RPS outlet is positioned at an angle substantially ninety degrees from the valve opening connected to the process chamber inlet. The nosepiece typically includes a sealing element or o-ring that gets compressed against the valve body surrounding one of the valve openings in order to close the gas flow path. Other valves have a straight valve body arranged such that the gas flow path between the RPS outlet and process chamber inlet is substantially horizontal, and the piston is positioned at an angle to the valve body.

[0007] One issue with the valves described above is that semiconductor processing systems are often installed within a facility having limited physical space, and such valves can be large due to the space needed to support the stroke length needed to retract the valve nosepiece. Further, even in the fully open position, the bellows and nosepiece cannot be sufficiently retracted by the piston to be obscured from the path of reactive gasses flowing through the valve body. This reduces the transport efficiency of the reactive gas generated by the RPS that reaches the process chamber due to recombination reactions caused by collisions with the valve bellows and nosepiece. Additionally, when reactive gasses flowing from the RPS contact the surface of the bellows and nosepiece, there is an exothermic reaction that quickly generates enough heat to raise valve components to excessive temperatures outside of their recommended operating range. Accordingly, some valves include channels routed through the valve body and in some cases the nosepiece to allow cooling fluids to be circulated. In addition to these thermal concerns, any stainless steel components such as the valve bellows can cause recombination of reactive gas and loss of transport efficiency.

[0008] However, despite the improvements that have been made to address cooling and the corrosion of certain valve components, degradation of the sealing element or o-ring remains a significant enough problem in conventional isolation valves that they are rarely used in the direct flow path between the RPS and process chamber. For example, o-rings are typically fabricated from a perfluoroelastomer material such as DuPont's Kalrez® or Greene

Tweed's Chemraz® products. These materials degrade quickly when exposed to reactive gasses such as atomic fluorine, and the speed of degradation is compounded when the gas that the materials are being exposed to is flowing at a high velocity. In particular, the face or sealing surface of the o-ring is subject to the most mechanical stress and is exposed to the most chemical attack, and therefore degrades at a rapid rate.

SUMMARY

[0009] There is therefore a need for multi-position isolation valves and related methods of use for preventing the degradation of the valve sealing element. There is also a need for multi-position isolation valves and related methods of use for enabling the remote plasma source and valve body to be purged simultaneously with semiconductor fabrication processes. Further, there is a need for multi-position isolation valves capable of providing a gas flow path through the valve aperture that can be fully open.

[0010] The isolation valve described herein overcomes the deficiencies of conventional isolation valves, in part, by exposing far less of the faces or sealing surfaces of its o-rings to reactive gasses and corrosive chemicals passing through the valve body. Accordingly, degradation of the o-rings is significantly reduced which can substantially increase the life expectancy or useable life of the o-rings as compared to those used in conventional isolation valves. For example, the useable life of an o-ring having the features of the isolation valve technology described herein can increase the useable life of an o-ring by several times to that of a conventional isolation valve. Further, the isolation valve described herein enables the gas flow path through the valve aperture to be fully open and unobstructed by other valve components such as a valve nosepiece or a change in direction of the gas flow path through the valve.

[0011] The technology, in one aspect, features an isolation valve assembly. The isolation valve assembly includes a valve body having an inlet and an outlet. The isolation valve assembly further includes a seal plate disposed within an interior cavity of the valve body. The seal plate is movable between a first position allowing gas flow from the inlet to the outlet, and a second position preventing gas flow from the inlet to the outlet. The isolation valve assembly further includes a closure element disposed within the valve body configured to retain the seal plate stationary in the first position or the second position. The closure

element includes a first sealing element positioned adjacent to a first surface of the seal plate. A working surface of the first sealing element is substantially obscured from the gas flow when the seal plate is stationary.

[0012] The isolation valve technology can further include any of the following features. In some embodiments, the closure element further includes a second sealing element positioned adjacent to a second surface of the seal plate. In some embodiments, a working surface of the second sealing element is substantially obscured from the gas flow when the seal plate is stationary. In some embodiments, the closure element is configured to use a compressive force to retain the seal plate stationary in the first position or the second position.

[0013] In some embodiments, the first sealing element provides a seal substantially preventing gas flow between the closure element and the first surface of the seal plate when the seal plate is stationary. In some embodiments, the second sealing element provides a seal substantially preventing gas flow between the closure element and the second surface of the seal plate when the seal plate is stationary.

[0014] In some embodiments, the isolation valve assembly further includes a first aperture formed in the valve body for receiving a purge gas into the interior cavity of the valve body, and a second aperture formed in the valve body for removing one or more of the purge gas and a residual gas from the interior cavity of the valve body. In some embodiments, the second aperture is formed in the valve body at a position remote from the first aperture. In some embodiments, the second aperture is formed in the valve body at a position on an opposite side of the seal plate as the first aperture. In some embodiments, the second aperture is formed in the valve body at a position that substantially maximizes the flow path between the second aperture and the first aperture within the interior cavity of the valve body.

[0015] In some embodiments, the seal plate further includes a channel directing gas flow from the inlet to the interior cavity of the valve body when the seal plate is in the second position. In some embodiments, the isolation valve assembly further includes a plurality of injection ports for injecting one or more chemical species into the gas flow when the seal plate is in the first position. In some embodiments, the plurality of injection ports are formed

in the seal plate, in the valve body between the seal plate and the inlet, or in the valve body between the seal plate and the outlet.

[0016] In some embodiments, the seal plate is movable between the first position and the second position about a pivot point in a rotational motion. In some embodiments, the seal plate further comprises at least one fluid channel in communication with a fluid inlet of the pivot point. In some embodiments, the seal plate is movable between the first position and the second position in a linear motion.

[0017] In some embodiments, a height of the isolation valve assembly is between about 1.5 and about 2 times the measured diameter of either of the inlet and the outlet.

[0018] The technology, in another aspect, features a method for directing an output of a remote plasma source operation through a valve body of an isolation valve assembly. The method includes securing an outlet of the remote plasma source to an inlet of the valve body of the isolation valve assembly. The method further includes positioning a seal plate disposed within an interior cavity of the valve body in a first position. The seal plate includes a channel directing gas flow from the inlet of the valve body to the interior cavity of the valve body when the seal plate is in the first position. The method further includes providing the output of the remote plasma source operation to the inlet of the valve body via the outlet of the remote plasma source and evacuating the output of the remote plasma source operation from a first aperture disposed in the valve body.

[0019] The method can further include any of the following features. In some embodiments, evacuating further includes simultaneously performing a semiconductor processing operation in a process chamber in fluid communication with an outlet of the isolation valve assembly. In some embodiments, the output of the remote plasma source operation includes one or more of a purge gas from a gas inlet of the remote plasma source to the outlet, a gas generated during a passivation process performed in a chamber of the remote plasma source, and a reactive species generated by a plasma formed in a chamber of the remote plasma source. In some embodiments, the method further includes flowing a purge gas from a gas inlet of the remote plasma source to the outlet of the remote plasma source.

[0020] In some embodiments, the method further includes performing a passivation process in a chamber of the remote plasma source, and flowing a gas generated during the passivation process to the outlet of the remote plasma source. In some embodiments, the method further includes forming a plasma in a chamber of the remote plasma source, and flowing a reactive species generated by the plasma to the outlet of the remote plasma source. In some embodiments, the plasma is an argon plasma or oxygen plasma.

[0021] In some embodiments, the method further includes supplying a purge gas to a second aperture disposed in the valve body and evacuating the purge gas and from the first aperture disposed in the valve body. In some embodiments, evacuating the output of the remote plasma source operation occurs substantially simultaneously with evacuating the purge gas. In some embodiments, evacuating a residual gas from the first aperture disposed in the valve body.

[0022] The technology, in another aspect, features a method for reacting a chemical species with a reactive species. The method includes securing an outlet of a remote plasma source to an inlet of a valve body of an isolation valve assembly. The method further includes positioning a seal plate disposed within an interior cavity of the valve body in a first position. The seal plate comprises a channel directing gas flow from the inlet of the valve body to an outlet of the valve body. The method further includes supplying a reactive species generated in the remote plasma source to the inlet of the valve body and injecting one or more chemical species into the reactive species via a plurality of injection ports formed in the seal plate.

[0023] In another aspect, the present technology features an isolation valve assembly that includes a valve body having an inlet and an outlet. The isolation valve assembly also includes a sealing body disposed within an interior cavity of the valve body. The sealing body comprises a channel extending between a first opening on a surface of the sealing body and a second opening on an opposite surface of the sealing body. The sealing body is rotatable between a first position permitting gas flow from the inlet to the outlet of the valve body via the channel, and a second position preventing gas flow from the inlet to the outlet of the valve body. The isolation valve assembly further includes an actuatable closure element disposed within the valve body. The actuatable closure element is configured to retain the sealing body stationary in the first position or the second position.

[0024] In some embodiments, the sealing body is substantially spherical. In some embodiments, the sealing body is volumetric with a plurality of facets.

[0025] In some embodiments, in the first position, the inlet of the valve body is substantially aligned with the first opening of the channel of the sealing body and the outlet of the valve body is substantially aligned with the second opening of the channel of the sealing body. In some embodiments, in the second position, the inlet of the valve body is substantially aligned with a first sealing surface of the sealing body and the outlet of the valve body is substantially aligned with a second sealing surface of the sealing body. The first and second sealing surfaces are configured to substantially seal respective ones of the inlet and outlet of the valve body in the second position. In some embodiments, in the second position, the channel is oriented substantially perpendicular to an axis extending between the inlet and the outlet of the valve body.

[0026] In some embodiments, the closure element is further configured to release physical contact with the sealing body when the sealing body is moving between the first and second positions. In some embodiments, the closure element is configured to use a compressive force to retain the sealing body stationary in the first position or the second position. In some embodiments, the closure element comprises at least one O-ring configured to form a seal against an outer surface of the sealing body to retain the sealing body stationary.

[0027] In some embodiments, the isolation valve assembly further includes a first aperture formed in the valve body for receiving a purge gas into the interior cavity of the valve body and a second aperture formed in the valve body for removing one or more of the purge gas and a residual gas from the interior cavity of the valve body. The second aperture is formed in the valve body at a position remote from the first aperture.

[0028] In some embodiments, the sealing body further comprises at least one bypass channel configured to direct a purge gas from the inlet of the valve body to the interior cavity of the valve body when the sealing body is in the second position. In some embodiments, the isolation valve assembly further comprises an actuator in electrical communication with the sealing body for rotating the sealing body between the first position and the second position about an axis of rotation.

[0029] In some embodiments, the isolation valve assembly further comprises at least one injection feed channel configured to inject one or more chemical species into the gas flow in the channel when the sealing body is in the first position. In some embodiments, the at least one injection feed channel is formed in at least one of the sealing body, the valve body between the sealing body and the inlet, or the valve body between the sealing body and the outlet.

[0030] In some embodiments, a height of the isolation valve assembly is between about 1.5 to about 2 times the measured diameter of at least one of the inlet or the outlet of the valve body.

[0031] In yet another aspect, a method is provided for directing an output of a remote plasma source operation through a valve body of an isolation valve assembly. The method includes securing an outlet of the remote plasma source to an inlet of the valve body of the isolation valve assembly that includes a rotatable sealing body disposed within an interior cavity of the valve body. The method includes rotating the sealing body within the interior cavity of the valve body to achieve an open position in which a first opening of a channel of the sealing body is substantially aligned with the inlet of the valve body and a second opening of the channel of the sealing body is substantially aligned with an outlet of the valve body. The method also includes providing the output of the remote plasma source operation to the inlet of the valve body via the outlet of the remote plasma source, and directing, in the open position, the output from the inlet of the valve body to the channel disposed in the sealing body. The method further includes evacuating the output of the remote plasma source operation from the channel of the sealing body via the outlet of the valve body.

[0032] In some embodiments, the method further includes flowing, in the open position, a reactive gas species from the remote plasma source to a process chamber via the valve body. The outlet of the valve body of the isolation valve assembly can be secured to an inlet of the process chamber. The method can further includes injecting one or more chemical species into the reactive species via one or more injection ports formed in at least one of the sealing body, the valve body between the sealing body and the inlet, or the valve body between the sealing body and the outlet.

[0033] In some embodiments, the method further includes rotating the sealing body within the interior cavity of the valve body to achieve a closed position at which a first sealing surface on the sealing body is substantially aligned with the inlet of the valve body to fluidly seal the inlet, and a second sealing surface on the sealing body is substantially aligned with the outlet of the valve body to fluidly seal the outlet. The closed position prevents gas flow from the inlet of the valve body to the outlet of the valve body. In some embodiments, the method further includes directing, in the closed position, the output from the inlet of the valve body to the interior cavity of the valve body via a bypass channel disposed in the sealing body and evacuating, in the closed position, the output from an outlet aperture disposed in the valve body. The outlet aperture is different from the outlet of the valve body.

[0034] In some embodiments, in the closed valve position, evacuating the output of the remote plasma source further includes simultaneously performing a semiconductor processing operation in a process chamber. The outlet of the valve body of the isolation valve assembly can be secured to an inlet of the process chamber. In some embodiments, the output of the remote plasma source operation comprises one or more of a purge gas from the remote plasma source or a gas generated during a passivation process performed in a chamber of the remote plasma source.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] The advantages of the systems and methods described herein, together with further advantages, may be better understood by referring to the following description taken in conjunction with the accompanying drawings. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the described embodiments by way of example only.

[0036] FIG. 1A is a block diagram of a semiconductor processing system including an isolation valve according to embodiments of the technology described herein.

[0037] FIG. 1B is a block diagram of a semiconductor processing system including isolation valves according to embodiments of the technology described herein.

[0038] FIG. 2 is a diagram of an RPS connected to an isolation valve according to embodiments of the technology described herein.

[0039] FIG. 3A is a diagram of a first embodiment of an isolation valve according to embodiments of the technology described herein.

[0040] FIG. 3B is a diagram showing 3 views of a second embodiment of an isolation valve according to embodiments of the technology described herein.

[0041] FIG. 4A is a diagram illustrating the rotational motion of a seal plate of an exemplary isolation valve according to embodiments of the technology described herein.

[0042] FIG. 4B is a diagram illustrating the linear motion of a seal plate of an exemplary isolation valve according to embodiments of the technology described herein.

[0043] FIG. 5 is a cross-sectional diagram of an exemplary isolation valve according to embodiments of the technology described herein.

[0044] FIG. 6A is a block diagram of an RPS connected to an isolation valve according to embodiments of the technology described herein.

[0045] FIG. 6B is a cross sectional diagram an RPS connected to an isolation valve according to embodiments of the technology described herein.

[0046] FIG. 7A is a cross sectional diagram of an exemplary isolation valve in a first operational mode according to embodiments of the technology described herein.

[0047] FIG. 7B is a cross sectional diagram of an exemplary isolation valve in a second operational mode according to embodiments of the technology described herein.

[0048] FIG. 7C is a cross sectional diagram of an exemplary isolation valve in a third operational mode according to embodiments of the technology described herein.

[0049] FIG. 7D is a cross sectional diagram of an exemplary isolation valve in a fourth operational mode according to embodiments of the technology described herein.

[0050] FIG. 8 is a flow diagram of a method for directing an output of a remote plasma source operation through a valve body of an isolation valve assembly, according to embodiments of the technology described herein.

[0051] FIG. 9 is a flow diagram of a method for reacting a chemical species with a reactive species, according to embodiments of the technology described herein.

[0052] FIG. 10 is a sectional view of another exemplary isolation valve, according to embodiments of the technology described herein.

[0053] FIG. 11 is a cross-sectional view of the valve body of the isolation valve of FIG. 10, according to embodiments of the technology described herein.

[0054] FIGS. 12a and 12b show respective ones of a first (open) position and a second (closed) position of the sealing body within the isolation valve of FIG. 10, according to embodiments of the technology described herein.

[0055] FIG. 13 illustrates a set of exemplary dimensions of the isolation valve of FIG. 10, according to embodiments of the technology described herein.

[0056] FIG. 14 shows a cross-sectional view of an exemplary configuration of the valve body of the isolation valve of FIG. 10 with integrated cooling features, according to embodiments of the technology described herein.

[0057] FIG. 15 is a block diagram of a remote plasma source (RPS), such as the RPS of FIG. 2, connected to the isolation valve of FIG. 10, according to embodiments of the technology described herein.

[0058] FIG. 16 illustrates another exemplary configuration of the isolation valve of FIG. 10 with components configured to perform purging of the isolation valve, according to embodiments of the technology described herein.

[0059] FIG. 17 illustrates another exemplary configuration of the isolation valve of FIG. 10 with components configured to perform chemical injection into the isolation valve, according to embodiments of the technology described herein.

[0060] FIG. 18 illustrates a flow diagram of a method for directing an output of a remote plasma source operation through the isolation valve of FIG. 10, according to embodiments of the technology described therein.

[0061] FIG. 19 illustrates an exploded view of an exemplary configuration of the isolation valve of FIG. 10, according to embodiments of the technology described therein.

DETAILED DESCRIPTION

[0062] FIG. 1A is a block diagram of a semiconductor processing system 100a including an isolation valve according to embodiments of the technology described herein. System 100a includes remote plasma source 104 (hereinafter, “RPS 104”) in communication with process chamber 106 via isolation valve 110. Process chamber 106 is in communication with isolation valve 110b, which in turn is in communication with throttle valve 126. In some embodiments, throttle valve 126 is a T3B throttle valve manufactured by MKS Instruments, Inc. of Andover, MA. Pump 108 is in communication with isolation valve 110 and an output of throttle valve 126 for circulating gasses within the components of system 100a. Gas distribution 102 is in communication with RPS 104, isolation valve 110, process chamber 106, and isolation valve 110b.

[0063] RPS 104 generates an active gas species for use in a semiconductor fabrication process. For example, using gasses supplied by gas distribution 102, RPS 104 can ignite a plasma and generate a reactive gas (e.g. atomic fluorine) typically used to clean a process chamber (e.g., process chamber 106) after a deposition process. In some embodiments, RPS 104 is an ASTRON® remote plasma source manufactured by MKS Instruments, Inc. of Andover, MA.

[0064] Isolation valve 110 can be installed in the path between RPS 104 and process chamber 106 to provide a flow path for the reactive gas when isolation valve 110 is in an

open position, and for isolating RPS 104 from process chamber 106 when isolation valve 110 is in a closed position. RPS 104 is isolated from process chamber 106 during deposition operations to prevent, for example, gasses from process chamber 106 from making their way up into the RPS and condensing or depositing a film on the chamber walls of RPS 104. Isolating RPS 104 from process chamber 106 with such a valve also allows RPS 104 to be purged and/or reconditioned/passivated with alternate process gas(es) without affecting processes being carried out in process chamber 106. Further, as described herein, isolation valve 110 can include features allowing its valve body to be purged with a purge gas supplied by gas distribution 102 and removed from the valve body via pump 108. For example, isolation valve 110 can include one or more inlet ports for injecting a gas into the valve body, and one or more outlet ports for drawing gas from the valve body. The purging and/or reconditioning/passivation operations can be performed simultaneously with processes being carried out in process chamber 106 if desired. Advantageously, this can decrease the unproductive downtime of the semiconductor processing system that would typically be necessary for performing maintenance operations.

[0065] Isolation valve 110 can also include features to enable injection of substances downstream of RPS 104 for enhancing the semiconductor processing operations performed in process chamber 106. In some embodiments, isolation valve 110 includes features enabling water vapor or other process gasses to be injected into the stream of reactive gas provided from RPS 104.

[0066] Gas distribution 102 represents several sources of gas and supplies all of the gasses used by the components of system 100a to carry out the various processes described herein. Gas distribution 102 includes RPS supply 112 which represents sources of one or more process gasses supplied to RPS 104. For example, NF_3 and Ar are typically used for chamber clean. Certain cleaning, etching, or photoresist strip applications may use NH_3 , H_2 , O_2 , or other gasses. RPS supply 112 also represents sources of one or more gasses used to purge RPS 104 (e.g., Ar, N_2). Gas distribution 102 also includes valve purge 114 which represents sources of one or more gasses used to purge isolation valve 110 (e.g., Ar, N_2), and downstream inject 116 which represents sources of one or more gasses injected downstream of RPS 104 (e.g., water vapor, N_2 , H_2 , NH_3 , O_2). Finally, gas distribution 102 includes primary process 118 which represents sources of one or more process gasses used in process chamber 106 (e.g., TEOS, O_3 , Silane, O_2).

[0067] Although shown in FIG. 1A as a single component, one of ordinary skill in the art will appreciate that gas distribution 102 can be made up of several gas sources and other supporting components that are not physically collocated with one another. One of ordinary skill in the art will further appreciate that the arrows in FIG. 1A showing the flow direction and connection paths between the various components of system 100a can be implemented as more than one physical path in practice, and that each component of system 100a can comprise a plurality of components. For example, although pump 108 is shown as a single pump for drawing gas from both process chamber 106 and isolation valve 110, in practice pump 108 may comprise one or more pumps for drawing gas from a point downstream of throttle valve 126, and an additional one or more pumps for drawing purge gas from isolation valve 110.

[0068] FIG. 1B is a block diagram of a semiconductor processing system 100b including isolation valves according to embodiments of the technology described herein. System 100b includes many of the same components as system 100a, but alternatively includes isolation valve 110b in place of isolation valve 124. (Unless a specific version of the system is referenced, system 100a and system 100b are hereinafter referred to interchangeably as “system 100.”) Further, valve purge 114 is in fluid communication with isolation valve 110b which is in fluid communication with the output of throttle valve 126 and pump 108.

[0069] In system 100b, isolation valve 110b can be the same type of valve as isolation valve 110 to enhance the performance of the system. For example, conventional isolation valves positioned at the outlet of a process chamber are typically subject to buildup of the byproducts of the processes (e.g., SiO₂, SiN, or metal oxide deposition processes) carried out in the process chamber. Byproducts from such processes (e.g., SiO₂, SiN, or metal oxide powder) tend to collect on the seat surfaces of conventional isolation valves, consequently causing the valves to fail to seal properly. Accordingly, using the isolation valve described herein between process chamber 106 and throttle valve 126 can provide advantages for semiconductor processes based on the features of the isolation valve discussed throughout this disclosure. For example, the enhanced ability of the isolation valve to shield the o-ring from reactive species and process byproducts can improve the valve's ability to maintain a positive seal. Further, the valve's ability to be purged by gasses from valve purge 114 can further reduce or eliminate the negative effects of byproduct buildup on the sealing ability of the valve in that location.

[0070] FIG. 2 is a diagram 200 showing an exemplary RPS connected to an isolation valve according to embodiments of the technology described herein. As shown in diagram 200, isolation valve 110 can be mounted directly or adjacent to an outlet of RPS 104.

[0071] FIG. 3A is a diagram 300a of a first embodiment of an isolation valve according to embodiments of the technology described herein. Isolation valve 310a comprises valve body 345a, which generally has a rectangular cuboid shape. Seal plate 305a is contained within valve body 345a, and pivots about pivot point 315a to expose different portions of seal plate 305a to aperture 330a to allow or prevent the flow of gas through aperture 330a. As used throughout the specification in reference to isolation valve technology, the term aperture can refer to the full flow path through which a gas is permitted to flow, or prevented from flowing, through the valve body, including any inlet(s) and outlet(s). An inlet can refer to an opening or conduit into which a gas or other substance flows, and an outlet can refer to an opening or conduit from which a gas or other substance flows. In some embodiments, a pneumatic actuator is used to apply a rotational force to pivot point 315a to control which portion of seal plate 305a is exposed to aperture 330a. In some embodiments, a mechanical or electromechanical actuator is used to apply a rotational force to pivot point 315a.

[0072] As shown in FIG. 3A, seal plate 305a is a “double throw” seal plate including a first portion including an opening for allowing the flow of gas through aperture 330a, and a second portion that blocks the flow of gas through aperture 330a. In some embodiments, seal plate 305a includes a plurality of portions having openings of different sizes, each of which allows a different amount of gas flow through aperture 330a.

[0073] FIG. 3B is a diagram showing 3 views of a second embodiment of an isolation valve according to embodiments of the technology described herein. View 300b-1 is an outline drawing of isolation valve 310b with its surfaces made transparent. View 300b-2 is an outline drawing of isolation valve 310b. View 300b-3 is an outline drawing of a cross section of isolation valve 310b.

[0074] The components of isolation valve 310b are similar to isolation valve 310a, but the size and shape of valve body 345b has been optimized around the dimensions of seal plate 305b in isolation valve 310b. The reduced size of the optimized valve body 345b can be beneficial to the installation of system 100, which is often within a facility having limited

physical space. In some embodiments, the body of the isolation valve has an irregular shape (e.g., kidney shape), a triangular shape, or a box shape to best accommodate the physical space in which the isolation valve is installed.

[0075] FIG. 4A is a diagram 400a illustrating the rotational motion of a seal plate of an exemplary isolation valve according to embodiments of the technology described herein. For example, isolation valve 410a can include seal plate 405a configured to rotate within the valve body about pivot point 415a in a rotational motion 422a. Alternatively, as shown in diagram 400b of FIG. 4B, seal plate 405b can move within isolation valve 410b according to a linear motion 422b. In some embodiments, the type of motion of the seal plate can be chosen to best fit within the physical location in which the semiconductor processing system is installed. Further, although seal plates 405a and 405b in FIGS. 4A and 4B, respectively, are shown as having two positions, embodiments of the valve technology described herein can include a seal plate having three or more positions, and can also incorporate features of other embodiments described herein.

[0076] An isolation valve according to embodiments of the technology described herein can include one or more closure elements configured to retain the seal plate stationary in a fixed position. Further, the closure elements can include a sealing element (e.g., o-ring, gasket, etc.) positioned to contact a surface of the seal plate when the closure elements are actuated to retain the seal plate stationary in the fixed position.

[0077] FIG. 5 is a cross-sectional diagram 500 of an exemplary isolation valve 510 according to embodiments of the technology described herein. Isolation valve 510 includes valve body 545 which houses seal plate 505, bellows actuator feed-throughs 550a and 550b (collectively referred to as bellows actuators 550), upper pneumatic piston 515a and lower pneumatic piston 515b (collectively referred to as pistons 515), upper spring 535a and lower spring 535b (collectively referred to as springs 535), upper caliper 520a and lower caliper 520b (collectively referred to as calipers 520), upper primary seal 525a and lower primary seal 525b (collectively referred to primary seals 525), upper cap 595a and lower cap 595a (collectively referred to caps 595), and aperture 530. Aperture 530 can be formed in valve body 545 with portions above and below seal plate 505, and provides a path for the flow of gas from its inlet portion where gas is flowed or injected into, to its outlet portion from which a flow of gas exits isolation valve 510 when seal plate 505 is positioned accordingly.

Isolation valve 510 can also include structural components housing other sealing elements for preventing gas flow within areas of valve body 545 other than the interface between seal plate 505 and calipers 520.

[0078] In some embodiments, valve components such as valve body 545, seal plate 505, and calipers 520 are made from aluminum (e.g., 6061 aluminum) and anodized. In some embodiments, the height 502 of isolation valve 510 is 1.5 to 2 times the diameter of aperture 530. In some embodiments, height 502 is about 2 to about 5 times the diameter of aperture 530. Accordingly, the valve technology described herein provides isolation that meets or exceeds the specifications of a conventional poppet valve while maintaining the compact geometry of a conventional gate valve.

[0079] As depicted in FIG. 5, primary seals 525 are embedded in dovetail grooves formed in calipers 520. One of skill in the art will appreciate that other techniques can be used to secure or embed primary seals 525 to or in calipers 520. In some embodiments, primary seals 525 are embedded in the top and bottom sides of seal plate 505. In some embodiments, primary seals are embedded in calipers 520 and in the top and bottom sides of seal plate 505, and the primary seals are offset horizontally from each other.

[0080] As depicted in FIG. 5, isolation valve 510 incorporates two bellows actuator feed-throughs (upper bellows actuator feed-through 550a and lower bellows actuator feed-through 550b) located on opposite sides of valve body 545. In some embodiments, isolation valve 510 incorporates more than two bellows actuators. For example, one or more additional upper bellows actuators and one or more additional lower bellows actuators can be positioned on opposite sides of valve body 545 such that they are positioned substantially equidistant from bellows actuators 550, respectively. In some embodiments, the bellows component of the bellows actuators utilized for isolation valve 510 is formed from spring steel (e.g., stainless steel). In some embodiments, a thin coating of aluminum oxide is applied to the outer surface of each bellows as a measure to reduce corrosion caused by exposure to reactive species generated in plasmas such as fluorine-based plasmas. In some embodiments, the bellows are coated with an ALD Al_2O_3 coating. One of skill in the art will appreciate that in some embodiments, isolation valve 510 can alternatively incorporate dynamic linear slide actuators or slide seals in place of bellows actuators 550.

[0081] During operation, pneumatic actuators (not shown) secured to the top and bottom of valve body 545 simultaneously apply pressure to pistons 515 causing them to travel vertically and compress springs 535 mounted between valve body 545 and pistons 515, and also compress the bellows components of bellows actuators 550. The vertical, linear movement of pistons 515 causes a vertical rod or stem within each of bellows actuators 550 to travel vertically and apply a corresponding linear force against calipers 520, respectively. Calipers 520 are configured to have a range of vertical motion within valve body 545 through which they can travel. In some embodiments, each of calipers 520 has a range of vertical motion of less than 1mm. In some embodiments, each of calipers 520 has a range of vertical motion of about 0.5mm to about 3mm. In some embodiments, each of calipers 520 has a range of vertical motion of about 3mm to about 5mm.

[0082] The force applied to calipers 520 by bellows actuators 550 in turn causes calipers 520 to be pressed firmly against seal plate 505, which simultaneously locks seal plate 505 in place and compresses primary seals 525 against seal plate 505. This has the advantageous effect of substantially sealing off valve body 545 from exposure to any corrosive or etchant gasses that pass through aperture 530 when seal plate 505 is in a position that enables gas flow (as depicted in FIG. 5), and likewise substantially prevents process gasses from process chamber 106 and any remaining corrosive or etchant gasses from RPS 104 from entering valve body 545 when seal plate 505 is in a position that prevents the flow of gas through aperture 530.

[0083] A further advantage of the configuration of isolation valve 510 is that far less of the working surface of each of primary seals 525 is exposed to the flow of corrosive or etchant gasses passing through aperture 530 as compared to conventional isolation valves. For example, the primary sealing element of a state-of-the-art right angle poppet valve is typically an o-ring mounted in the end face of a nosepiece that is retracted and extended to open and close the gas flow path through the valve. In the closed position, the nosepiece is fully extended and the primary sealing element is compressed against a seat surface of the valve aperture inlet, leaving only a small portion of the primary sealing element exposed to gasses that may flow into a small gap between the nosepiece and seat surface. However, when the nosepiece is retracted to open the valve, up to 50% of the surface of the primary sealing element is directly in the path of gas flowing into the inlet of the valve, even if the

nosepiece is retracted beyond the top of the valve outlet, which is typically not practicable due to physical constraints.

[0084] This configuration of a conventional right angle poppet valve can be the source of several negative effects. First, the primary sealing element is typically fabricated from a perfluoroelastomer material that can degrade quickly when exposed to reactive gasses such as atomic fluorine, and the speed of degradation can be compounded when the gas is flowing at a high velocity. Accordingly, the useable life of the primary seal used in a conventional right angle poppet valve can be less than desired under conditions necessary for certain processes. Further, the transport efficiency of the system is negatively-impacted as gasses such as atomic fluorine are subject to a higher degree of loss as they flow through the valve due to recombination caused by collisions with the nosepiece, the primary sealing element, and the walls of the aperture which include a right angle turn in the path between the valve inlet and outlet. In addition, because the nosepiece typically cannot be fully retracted due to physical constraints, a portion of it protrudes into the valve aperture, reducing the maximum achievable gas flow rate through the valve an increasing recombination. Even when using valves designed to have a stroke length sufficient to fully retract the nosepiece (which typically renders them impractical from a physical size standpoint), there is still a loss due to recombination, as the nosepiece and primary sealing element are exposed to the flow of gas, even if only tangentially. Finally, recombination is an exothermic reaction that generates a large amount of heat which gets conducted into the components of the valve. Temperatures within the valve body can quickly exceed the rated operating temperature of the primary sealing element (typically around 210° C), and reach 300° C or more.

[0085] One alternative to the right angle poppet valve is an inline valve with an angled seat, which can reduce some of the negative effects discussed above. For example, when the nosepiece of such an inline valve is retracted to open the valve, the primary sealing element is typically not located directly in the path of gas flowing between the valve inlet and the valve outlet, which are horizontally aligned to form a straight flow path. This configuration can reduce the number of collisions between gasses flowing through the valve aperture and components of the valve such as the nosepiece, the primary sealing element, and the walls of the aperture. However, there is still a pronounced loss of transport efficiency due to recombination, as the nosepiece and primary sealing element are exposed to the flow of gas, even if only tangentially. Further, while the useable life of an angle seat isolation valve

primary sealing element can typically exceed that of the right angle poppet valve primary sealing element, it is still markedly deficient under certain conditions. For example, the portion of the primary sealing element located closest to the valve inlet when the angle seat valve is open degrades at an accelerated rate when exposed to volumes of gas flowing at a high velocity.

[0086] In contrast to the right angle poppet valve and inline isolation valve, the isolation valve 510 described herein significantly reduces or eliminates the negative effects described above. As an initial matter, the configuration of isolation valve 510 substantially obscures primary seals 525 from any corrosive or etchant gasses regardless of whether seal plate 505 is positioned such that the gas flow path through aperture 530 is fully open, partially open, or closed because only a minimal portion of each of primary seals 525 are exposed. In part, this is because primary seals 525 are compressively sealed against seal plate 505 during operation of isolation valve 510. When primary seals 525 are compressed against seal plate 505, there are only small crevices or gaps (e.g., gap 540a and gap 540b, collectively referred to as “gaps 540”) between the top and bottom surfaces of seal plate 505 and the respective surfaces of valve body 545 and calipers 520. In some embodiments, between about 0.5% and about 1% of the surface of each of primary seals 525 is exposed to gasses flowing through gaps 540 when primary seals 525 are in a compressed state. In some embodiments, between about 1% and about 5% of the surface of each of primary seals 525 is exposed to gasses flowing through gaps 540 when primary seals 525 are in a compressed state. In some embodiments, between about 5% and about 10% of the surface of each of primary seals 525 is exposed to gasses flowing through gaps 540 when primary seals 525 are in a compressed state.

[0087] In addition, gasses resident in, or flowing through, aperture 530 can only reach primary seals 525 via gaps 540 by traveling perpendicular to the main flow of gas. Even then, a corrosive gas such as atomic fluorine is typically reduced to a less corrosive and reactive form (e.g., molecular fluorine) by recombination reactions caused by collisions of the atomic fluorine with surfaces of valve body 545 and seal plate 505 as the gas makes its way through gaps 540 toward primary seals 525.

[0088] In some embodiments, valve body 545 is constructed such that the paths between primary seals 525 and gaps 540 are “labyrinths” having one or more direction changes. In such a configuration, the recombination effect of gasses flowing through gaps 540 can be

increased, further decreasing the likelihood that corrosive gasses are able to reach primary seals 525. In some embodiments, the position primary seals 525 are mounted on calipers 520 is varied to increase the horizontal distance between primary seals 525 and aperture 530, thereby increasing the number of collisions between a gas and the surfaces of valve body 545 and seal plate 505 as the gas makes its way through gaps 540 toward primary seals 525. In some embodiments, primary seals 525 are positioned about 5mm from aperture 530. In some embodiments, primary seals 525 are positioned between about 10mm and 20mm from aperture 530. In some embodiments, primary seals 525 are positioned between about 20mm and 40mm from aperture 530.

[0089] Reducing the exposure of the working surfaces of primary seals 525 can significantly increase the useable life of primary seals 525 as compared to comparably made primary sealing elements used in conventional isolation valves. In some embodiments, the useable life of primary seals 525 is increased by about 2 to 10 times the life of comparably made primary seals used in conventional isolation valves. In some embodiments, the useable life of primary seals 525 is increased by about 10 to 50 times the life of comparably made primary seals used in conventional isolation valves. In some embodiments, the useable life of primary seals 525 is more than 1000 hours of operation or up-time.

[0090] Returning to the operation of isolation valve 510, in order to release the compressive forces applied by calipers 520 to seal plate 505, the pneumatic actuators release the pneumatic loads being applied to pistons 515 and forces applied by springs 535 decompressing cause pistons 515, bellows actuators 550, and calipers 520 to return to their initial positions, freeing seal plate 505 to be rotated to other positions. As depicted in FIG. 5, only spring 535a and spring 535b are visible. However, it should be understood that valve 510 can include additional springs mounted between valve body 545 and piston 515b. In some embodiments, there are two or more springs mounted between each of pistons 515 and valve body 545.

[0091] The exemplary isolation valve 510 shown in FIG. 5 has a “spring-open” or “normally-open” configuration meaning that upon release of the pneumatic loads applied to pistons 515, forces applied by springs 535 return the corresponding components of isolation valve 510 to an “open” position that allows seal plate 505 to be rotated to a new position within valve body 545. One of skill in the art will appreciate that in some embodiments,

isolation valve 510 can alternatively have a “spring-close” or “spring-return” configuration. In such a configuration, pneumatic loads are applied to pistons 515 to cause the components of isolation valve 510 to move to an “open” position that allows seal plate 505 to be rotated to a new position within valve body 545, and springs return the corresponding components of isolation valve 510 to the compressed or “closed” position upon release of the pneumatic loads applied to pistons 515. Further, in some embodiments, isolation valve 510 can be constructed to have a “double-acting” or “dual pneumatic” configuration that uses forces applied by pneumatic actuators to alternate the corresponding components of isolation valve 510 between the open and closed/compressed states.

[0092] Once the compressive forces applied by calipers 520 are released, seal plate 505 can be repositioned to expose a different portion of seal plate 505 to aperture 530. For example, as described above in reference to FIG. 3A, a pneumatic actuator can be used to apply a rotational force to a pivot point (not shown in FIG. 5) to control which portion of seal plate 505 is exposed to aperture 530. In some embodiments, a mechanical or electromechanical actuator can be used to apply a rotational force to the pivot point to control the movement of seal plate 505. Once seal plate 505 has been rotated to the desired position, the process above is repeated to lock seal plate 505 in its new position within valve body 545 and to again compress primary seals 525 against seal plate 505.

[0093] Although described herein as distinct components, one of skill in the art will recognize that calipers 520 can be a unitary body or component, and can also be an assembly of two or more components. Further, in some embodiments of the isolation valve technology described herein, only one of primary seals 525 is compressively sealed against seal plate 505 during operation of isolation valve 510, therefore substantially obscuring or shielding one primary seal from any corrosive or etchant gasses passing through aperture 530. In some embodiments, isolation valve 510 comprises one primary seal.

[0094] In some embodiments, isolation valve 510 incorporates thermal management features to prevent overheating due to energy dissipated by chemical processes, and to maintain the temperature of isolation valve 510 above the condensation point of exposed processes. In some embodiments, valve body 545 and seal plate 505 include a plurality of fluid channels formed within them through which a gas or liquid coolant is flowed. In some embodiments, the liquid coolant is water, glycol, CDA, dielectric fluorine-based fluid from

Galden® or a similar liquid. In some embodiments, the coolant is supplied to the fluid channels of seal plate 505 via its pivot point. In some embodiments, one or more of pistons 515, bellows actuators 550, and calipers 520 incorporate fluid channels for circulating a coolant. In some embodiments, heat pipes are incorporated in the components of isolation valve 510 for thermal management. In some embodiments, components of isolation valve 510 use conduction for thermal management. In one example, thermal energy from calipers 520 is conducted to valve body 545 and seal plate 505 when primary seals 525 are in a compressed state.

[0095] FIG. 6A is a block diagram 600a of an RPS 104 connected to an isolation valve 610 according to embodiments of the technology described herein. Isolation valve 610 includes many of the same features and components as isolation valve 510. However, isolation valve 610 utilizes a plurality of pneumatic actuators (e.g., actuators 660) to extend and retract the calipers within valve body 645. In some embodiments, actuators 660 are based on International Organization for Standardization (“ISO”) valve actuators.

[0096] As depicted in FIG. 6A, isolation valve 610 incorporates eight actuators 660, with four upper actuators and four lower actuators located on opposite sides of valve body 645. In some embodiments, isolation valve 610 incorporates more than eight actuators 660.

[0097] FIG. 6B is a cross sectional diagram 600b of the embodiment shown in FIG. 6A. As shown, a vertical rod or stem within each of actuators 660 extends into caliper 620a or caliper 620b (collectively, “calipers 620”), respectively, depending on the location of each of actuators 660.

[0098] In operation, actuators 660 are operated substantially simultaneously to extend calipers 620 and compress primary seal 625a and primary seal 625b (collectively, “primary seals 625”) against seal plate 605. As shown in FIG. 6B, seal plate 605 is in a position within valve body 645 that closes the gas flow path through aperture 630. In order to change the position of seal plate 605, actuators 660 are operated substantially simultaneously to retract calipers 620, and seal plate 605 can be rotated to a new position within valve body 645 in a substantially similar manner as described above in reference to FIG. 5. As with the exemplary isolation valve 510 shown in FIG. 5, isolation valve 610 can have a “spring-open,” a “spring-close” or “spring-return,” or a “double-acting” or “dual pneumatic” configuration.

[0099] In some embodiments, seal plate 605 can include downstream injectors 690 for injecting a process or purge gas into aperture 630. In some embodiments, downstream injectors are formed in a portion of aperture 630 located between seal plate 605 and the outlet of RPS 104. In some embodiments, downstream injectors are formed in a portion of aperture 630 located below seal plate 605.

[0100] The next series of drawings illustrate several operational modes of the isolation valve technology described herein, and the corresponding description details the advantages the isolation valve provides.

[0101] FIG. 7A is a cross sectional diagram 700a of an exemplary isolation valve 710 in a first operational mode according to embodiments of the technology described herein. Isolation valve 710 includes similar elements to isolation valve 510 from FIG. 5. For example, among others, isolation valve 710 includes seal plate 705, aperture 730, and valve body 745, which are similar to seal plate 505, aperture 530, and valve body 545, respectively. In cross sectional diagram 700a, the upper piston, bellows actuator feed-throughs, caliper and primary seal are represented by 765a, and the lower piston, bellows actuator feed-throughs, caliper and primary seal are represented by 765b.

[0102] Isolation valve 710 further includes an aperture or inlet port 770 for injecting a purge gas (e.g., nitrogen, argon) from valve purge 114 into the interior cavity of valve body 745, and an aperture or outlet port 775 for evacuating the purge gas and residual process gas from the interior cavity of valve body 745 via pump 108. In some embodiments, inlet port 770 includes one or more inlet ports for injecting a purge gas into valve body 745. In some embodiments, outlet port 775 port includes one or more outlet ports for drawing gas from valve body 745. As shown in cross sectional diagram 700a, valve body 745 can be purged when seal plate 705 is in a position that prevents the flow of gas through aperture 730.

[0103] One of skill in the art will appreciate that it can be beneficial to the purge process to form outlet port 775 at a position in valve body 745 remote from inlet port 770 to substantially maximize the flow path of the purge gas through the interior cavity of valve body 745. For example, as depicted in FIG. 7A (and in FIGS. 7B-7D described below), outlet port 775 is positioned substantially on the opposite side of valve body 745 as inlet port 770. Further, although inlet port 770 and outlet port 775 are depicted as being formed in the

top and bottom surfaces of valve body 745, respectively, either or both of inlet port 770 and outlet port 775 can be formed in a top, side, or bottom surface of valve body 745 according to embodiments of the valve technology described herein. In some embodiments, multiple inlet and outlet ports are formed at various positions in valve body 745 and a subset of the inlet and outlet ports can be selectively utilized according to the type of purge process being performed or the area of the interior cavity the process is intended to purge.

[0104] FIG. 7B is a cross sectional diagram 700b of isolation valve 710 in a second operational mode according to embodiments of the technology described herein. In cross sectional diagram 700b, seal plate 705 is in a position that enables the flow of gas from an outlet of RPS 104 into an inlet portion of aperture 730, where the gas can continue to flow through aperture 730 via an opening in seal plate 705, and subsequently out of an outlet portion of aperture 730 to process chamber 106. For example, the flow of gas from RPS 104, depicted as double-headed arrows in FIG. 7B, can be an active gas species such as atomic fluorine. In some embodiments, the flow of gas from RPS 104 is a purge gas (e.g., nitrogen, argon), or a plasma (e.g., an argon-based plasma).

[0105] Accordingly, the configuration of isolation valve 710 allows valve body 745 to be purged whether seal plate 705 is in a position that prevents (e.g., FIG. 7A) or enables (e.g., FIG. 7B) the flow of gas through aperture 730. Purging valve body 745 advantageously removes backstream process gasses (e.g., fluorine, or deposition gasses) that seep into valve body 745 during processing and are otherwise trapped there. Continually or periodically purging valve body 745 can therefore extend the life of components such as the primary seals that can be deteriorated by exposure to residual process gasses.

[0106] FIG. 7C is a cross sectional diagram 700c of isolation valve 710 in a third operational mode according to embodiments of the technology described herein. In cross sectional diagram 700c, seal plate 705 is in a position that prevents the flow of gas from an outlet of RPS 104 through aperture 730 to process chamber 106. However, in this embodiment, seal plate 705 includes bypass port 780 formed through it providing a path from the RPS side of aperture 730 (e.g., the upper portion of aperture 730 as depicted in FIG. 7C) to the interior cavity of valve body 745. In some embodiments, bypass port 780 is made up of a plurality of ports formed within seal plate 705. Further, although seal plate 705 in FIG. 7C is shown as having two positions (e.g., “valve aperture open” and “valve aperture closed

with bypass”), as discussed above, some embodiments of seal plate 705 include three or more positions and incorporate features of other embodiments described herein.

[0107] A semiconductor processing system utilizing an isolation valve having bypass port 780 provides several advantages over conventional semiconductor processing systems. By way of background, in a conventional semiconductor processing system, during the periods when the RPS is not providing reactive gas to the process chamber, the RPS will be off. Although it is desirable to flow a purge gas (e.g., argon) through the RPS in this state to maintain a known chemistry within the RPS, this is often difficult to implement. There is a risk that the flow of the purge gas and gasses being evacuated by the purge process could interfere with or changes the dynamics of the deposition process occurring in the process chamber, as the flow path from the RPS to the exhaust of a conventional semiconductor processing system necessarily flows through the process chamber.

[0108] Due to these concerns, when the RPS is not in use generating a plasma, it is typically powered off and left in a “cold” state with reduced regulation of the chemistry of its internal environment. This can lead to some issues. For example, in the absence of the flow of a purge gas through the RPS, residual gasses, deposition gasses can migrate upstream and condense in the RPS, or upstream of the RPS. . If that byproduct is deposited upstream of where the plasma is generated by residual process gasses, it will not be removed during the chamber cleaning process and can become a perpetual source of particulate matter or contamination. Further, the temperature disparity between the hot gasses flowing upstream into the cold chamber of the RPS can cause condensation to form. Coupled with the unregulated chemistry of its internal environment when in the off state, re-ignition performance of the RPS can become inconsistent, which causes undesirable delays in semiconductor processing operations.

[0109] A semiconductor processing system utilizing the isolation valve technology described herein overcomes the deficiencies of conventional semiconductor processing systems. In particular, bypass port 780 enables valve body 745 and RPS 104 to be purged simultaneously while other processes (e.g., deposition) are carried out within process chamber 106. For example, a purge gas (e.g., nitrogen, argon) can be flowed through valve body 745 while simultaneously being flowed through the powered down or “passive” RPS 104 to prevent any process gasses from making their way upstream into RPS 104. Finally, a

known chemistry can be maintained within RPS 104, thereby eliminating or significantly reducing the RPS re-ignition issues experienced by conventional semiconductor processing systems.

[0110] In addition to providing the means for purging valve body 745 and RPS 104 when it is in a passive or powered down state, bypass port 780 also enables simultaneous purging of valve body 745 and RPS 104 while RPS 104 remains in a standby mode where it remains powered on and generating a plasma. For example, after the active gas species has been delivered to process chamber 106 and a subsequent deposition process is taking place, RPS 104 can remain powered on and continue to generate a plasma (e.g., argon plasma). A plasma generated using a gas such as argon is not aggressive enough to damage the components of isolation valve 710. Accordingly, RPS 104 does not need to be disabled before seal plate 705 can be rotated or moved from a position that allows the flow of gas through aperture 730 to a position that prevents the flow of gas through aperture 730, but provides a flow path from the outlet of RPS 104 to the interior of valve body 745 via bypass port 780.

[0111] Operation in this mode eliminates the issues with failed RPS re-ignition experienced with conventional semiconductor processing systems discussed above because RPS 104 is never powered down. Further, there is far less thermal cycling of RPS 104 when operating in this mode which subjects the components of RPS 104 to less thermal shock, and results in significantly less condensation being generated on the chamber surfaces of RPS 104 and on nearby components.

[0112] In addition, operation in the preceding mode allows preventative maintenance to be performed on RPS 104 without requiring its removal from system 100, and without affecting process chamber 106. In particular, with seal plate 705 positioned as shown in FIG. 7C, a plasma can be generated in RPS 104 with oxygen or another conditioning gas to passivate the surfaces of the chamber of RPS 104. For example, when performed on a remote plasma source having chamber surfaces comprised of anodized aluminum, this process can convert difluoroaluminum (AlF_2) and/or aluminum fluoride (AlF_3) that has formed on the chamber surfaces during operation to aluminum oxide (Al_2O_3). $\text{AlF}_2/\text{AlF}_3$ can detach from the surface walls over time and becomes a source of contaminating particles for wafers being processed. Accordingly, performing the passivation process before this occurs can reduce or

eliminate $\text{AlF}_2/\text{AlF}_3$ from the chamber surfaces, thereby prolonging the lifetime of the chamber block. Further, these conditioning and maintenance operations are not limited to processing chamber surfaces comprised of anodized aluminum. The valve technology described herein enables conditioning and maintenance processes to be performed on chamber surfaces comprised of materials such as quartz materials, sapphire materials, alumina, aluminum nitride, yttrium oxide, silicon carbide, boron nitride, and/or a metal such as aluminum, nickel or stainless steel.

[0113] FIG. 7D is a cross sectional diagram 700d of isolation valve 710 in a fourth operational mode according to embodiments of the technology described herein. In cross sectional diagram 700d, seal plate 705 is in a position that enables the flow of gas from an outlet of RPS 104 through aperture 730 to process chamber 106. However, in this embodiment, seal plate 705 includes one or more channels 785 formed within it for injecting different gasses or chemistries downstream of RPS 104. For example, seal plate 705 can include one or more inlets (not shown) in communication with downstream inject 116 for supplying a process or purge gas (e.g., chemical species, forming gas, water vapor) into channels 785 for injection into aperture 730 via one or more downstream injectors 790. In some embodiments, gas is supplied to channels 785 via a conduit in the pivot point (not shown) of seal plate 705.

[0114] As indicated above, system 100 is often installed within a facility having limited physical space. Accordingly, the described configuration of isolation valve 710 can provide a valuable space savings for system 100 since additional equipment does not need to be plumbed into the gas flow path in order to inject different gasses or chemistries downstream from RPS 104.

[0115] In some embodiments, one or both of channels 785 and downstream injectors 790 are formed in valve body 745 in the walls of aperture 730 below seal plate 705. In some embodiments, one or both of channels 785 and downstream injectors 790 are formed in valve body 745 in the walls of aperture 730 above seal plate 705. Downstream injectors 790 can be positioned either above or below the seal plate 705.

[0116] Further, although seal plate 705 in FIG. 7D is depicted as having two positions (e.g., “valve aperture closed” and “valve aperture open with downstream injection”), as

discussed above, some embodiments of seal plate 705 include three or more positions and incorporate features of other embodiments described herein.

[0117] FIG. 8 is a flow diagram of a method 800 for directing an output of a remote plasma source operation through a valve body of an isolation valve assembly, according to embodiments of the technology described herein. Method 800 includes securing (805) an outlet of the remote plasma source to an inlet of a valve body of the isolation valve assembly. For example, as described above in reference to system 100, the outlet of RPS 104 can be mounted directly or adjacent to an inlet of the valve body of isolation valve 110.

[0118] Method 800 further includes positioning (810) a seal plate disposed within an interior cavity of the valve body in a first position, wherein the seal plate comprises a channel directing gas flow from the inlet to the interior cavity of the valve body when the seal plate is in the first position. For example, an isolation valve having a seal plate with features described in FIG. 7C can be positioned as described in reference to FIG. 5 above to present a bypass path to gas flowing from RPS 104 into the valve inlet.

[0119] Method 800 includes providing (815) the output of the remote plasma source operation to the inlet of the valve body via the outlet of the remote plasma source, and evacuating (820) the output of the remote plasma source operation from a first aperture disposed in the valve body.

[0120] For example, a purge operation can be carried out in RPS 104. RPS supply 112 can supply a purge gas such as argon to a gas inlet of RPS 104. Referring again to FIG. 7C, the purge gas from RPS 104 (shown in FIG. 7C as lines having two points) can flow into the inlet of isolation valve 710 where bypass port 780 directs it to an interior cavity of valve body 745, and it is evacuating via outlet port 775.

[0121] In some embodiments, the output of the remote plasma source operation is a gas generated during a passivation process performed in RPS 104. In some embodiments, the output of the remote plasma source operation is a reactive species generated by a plasma (e.g., argon plasma, oxygen plasma) formed in RPS 104.

[0122] In some embodiments, valve body 745 is purged. For example, a purge gas can be supplied to inlet port 770, and can flow from inlet port 770 to outlet port 775 where it is evacuated by a vacuum created by pump 108. In some embodiments, at least one of residual gas and particulate matter are also evacuated from valve body 745.

[0123] In some embodiments, the remote plasma source operation and/or evacuation of the output of the remote plasma source operation occurs substantially simultaneously with the purging of valve body 745. Further, because seal plate 705 maintains isolation with process chamber 106 with seal plate 705 in this position, semiconductor processing operations can be performed simultaneously with any of the operations described above.

[0124] FIG. 9 is a flow diagram of a method 900 for reacting a chemical species with a reactive species, according to embodiments of the technology described herein. Method 900 includes securing (905) an outlet of a remote plasma source to an inlet of a valve body of an isolation valve assembly. For example, as described above in reference to system 100, the outlet of RPS 104 can be mounted directly or adjacent to an inlet of the valve body if isolation valve 110.

[0125] Method 900 further includes positioning (910) a seal plate disposed within an interior cavity of the valve body in a first position, wherein the seal plate comprises a channel directing gas flow from the inlet of the valve body to an outlet of the valve body. For example, an isolation valve having a seal plate with features described in FIG. 7D can be positioned as described in reference to FIG. 5 above to present a flow path from RPS 104 through isolation valve 710 and into an inlet of process chamber 106.

[0126] Method 900 includes supplying (915) a reactive species generated in the remote plasma source to the inlet of the valve body. For example, as described above, a reactive species can be generated in RPS 104 and flowed into isolation valve 710. Method 900 further includes injecting (920) one or more chemical species into the reactive species via a plurality of injection ports formed in the seal plate. For example, referring again to FIG. 7D, seal plate 705 can include one or more inlets (not shown) in communication with downstream inject 116 for supplying one or more chemical species into channels 785 for injection into aperture 730 via downstream injectors 790. Injection of the one or more chemical species into aperture 730 while the reactive species flow through can enhance or improve the effects

of the process. Further, the design of isolation valve 710 enables valve body 745 to be purged, as described above, substantially simultaneously with the steps of method 900.

[0127] FIG. 10 is a sectional view of another exemplary isolation valve 1000, according to embodiments of the technology described herein. The isolation valve 1000 can provide similar functionalities as the various isolation valve designs described above, such as isolation valve 510, while being compatible with, but not limited to, reactive gas services. As shown, the isolation valve 1000 generally defines an inlet 1004 and an outlet 1006 in open communication with an interior cavity 1008 disposed within a valve body 1002. The valve body 1002 is a mechanical housing configured to support one or more of sealing elements, porting of vacuum and gas feed channels, and thermal management of fluids or members. In some embodiments, a sealing body 1010 and a set of one or more closure elements (hereinafter referred to as calipers) 1012 are housed within the interior cavity 1008 of the valve body 1002 for selectively preventing and permitting gas flow from the inlet 1004 to the outlet 1006 of the isolation valve 1000. The sealing body 1010 can serve as the primary active element of the valve 1000. In some embodiments, the isolation valve 1000 additionally includes an actuator 1014 coupled to the valve body 1002 and in communication with the sealing body 1010 and/or the caliper(s) 1012. Alternatively, the actuator 1014 can be located external to and/or remote from the isolation valve 1000. The isolation valve 1000 can also include structural components that house other sealing elements for preventing and permitting gas flow within areas of the valve body 1002 in place of or in addition to the sealing body 1010 and the calipers 1012.

[0128] In some embodiments, the sealing body 1010 is a volumetric element, such as a substantially spherical element as depicted in FIG. 10. Alternatively, the sealing body 1010 can have a shape different from a sphere while still providing substantially the same functions as a sphere, such as an ovoid, cylindrical or square shape. The shape of the sealing body 1010 can be multi-faceted (e.g., 2, 3 or 4 facets) with one or more contoured (e.g., non-planar or generally non-planar) surfaces or generally planar surfaces. Further, as understood by a person of ordinary skill in the art, the remaining elements of the isolation valve 1000 can be suitably configured to accommodate the chosen shape of the sealing body 1010. As shown in FIG. 10, the sealing body 1010 generally defines a central channel 1018 extending between a first opening 1020 on a surface of the sealing body 1010 and a second opening 1022 on an opposite surface of the sealing body 1010. The first opening 1020 and the second opening

1022 can be substantially the same size as respectively ones of the inlet 1004 and outlet 1006 of the valve body 1002. In addition, the outer surface of the sealing body 1010 can define two sealing areas 1024, 1026 configured to form fluid impermeable seals against respectively ones of the inlet 1004 and outlet 1006 of the valve body 1002. These two sealing areas 1024, 1026 can be oriented at a certain rotational degree (e.g., 90 degrees) relative to the two openings 1020, 1022 on the sealing body surface.

[0129] In some embodiments, the sealing body 1010 is rotatable between (i) a first position (hereinafter referred to as “open” position) permitting gas flow from the inlet 1004 to the outlet 1006 of the valve body 1002 via the central channel 1018 of the sealing body 1010, and (ii) a second position (hereinafter referred to as “closed” position) preventing gas flow from the inlet 1004 to the outlet 1006 of the valve body 1002. The first and second positions can be achieved by rotating the sealing body 1010 within the interior cavity 1008 of the valve body 1002 by a predetermined rotational degree (e.g., 90 degrees).

[0130] Furthermore, the sealing body 1010 can include features for supporting one or more of assembly, porting for full gas flow, definition of vacuum sealing surfaces (such as by either surfacing or cutting a sealing element groove), and interfacing with thermal management, as described in detail below. Further, elements can be added to the sealing body 1010 to enhance functionalities of the isolation valve 1000, such as bypassing of incoming gas flow to other valve output ports, as described in detail below.

[0131] In some embodiments, the isolation valve 1000 includes one or more supports configured to provide bearing support of the sealing body 1010. These supports define, for example, an axis of rotation of the sealing body 1010 while providing features for centering the sealing body 1010 within the interior cavity 1008 the valve body 1002. In some embodiments, the supports integrate a set of translatable dynamic seals to provide vacuum sealing of the sealing body 1010 against external atmosphere. In some embodiments, the supports provide channels to enable cooling/thermal management of the internal valve elements. These supporting features are described below in detail.

[0132] FIG. 11 is a cross-sectional view of the valve body 1002 of the isolation valve 1000 of FIG. 10, according to embodiments of the technology described herein. FIG. 11 provides a more detailed view of the calipers 1012 and the accompanying elements that

enable movement of the calipers 1012 relative to the sealing body 1010. In general, the set of one or more calipers 1012 are actuatable to conform to the outer surface of the sealing body 1010 and provide a seal, such as a vacuum seal, between the sealing body 1010 and the interior cavity 1008 of the valve body 1002, while holding the sealing body 1010 substantially stationary within the valve body 1002. For example, the calipers 1012 can retain and vacuum seal the sealing body 1010 within an inner chamber 1114 of the interior cavity 1008 of the valve body 1002, where the inner chamber 1114 is defined by a set of inner walls 1106 and portions of the valve body 1002. As shown in FIG. 11, two dual-opposing calipers 1012 are used for creating seals against the outer surface of the sealing body 1010 relative to the valve body 1002. More specifically, each caliper 1012 provides actuatable sealing around an upper region or a lower region of the sealing body 1010. In other configurations, one caliper or more than two calipers can be used as reasonable to a person of ordinary skill in the art. In some embodiments, the set of one or more calipers 1012 are actuated pneumatically and operated in unison to apply substantially equal amounts of compressive force on the sealing body 1010 (e.g., toward the centroid of the sealing body 1010) to enable sealing while holding the sealing body 1010 stationary within the inner chamber 1114. One of skill in the art will appreciate that actuation of the calipers 1012 is not limited to pneumatics and can be achieved by other means, such as electrically using electrical solenoids.

[0133] As shown in FIG. 11, the set of calipers 1012 comprises an upper caliper 1012a and a lower caliper 1012b. In some embodiments, each caliper 1012 includes a circumferential plate 1011 with one or more circumferential mechanical arms 1102 having circumferential seals (e.g., O-rings) 1100 embedded in respective ones of dovetail grooves formed in the mechanical arms 1102. One of skill in the art will appreciate that other techniques can be used to secure or embed seals 1100 to or in calipers 1012. More specifically, each circumferential plate 1011 of a caliper 1012 can include two circumferential mechanical arms 1102a, 1102b (collectively referred to as 1102) having respective ones of a circumferential primary seal 1100a and a circumferential body seal 1100b (collectively referred to as seals 1100) secured thereto. The first mechanical arm 1102a – primary seal 1100a pair is configured to interface with an upper or lower surface of the sealing body 1010. The second mechanical arm 1102b – body seal 1100b pair is configured to secure the caliper 1012 to the top or bottom wall of the valve body 1002. The plate 1011 of each caliper 1012 is in turn connected to a piston 1104 coupled to the valve

body 1002, where the piston 1104 is configured to actuate the corresponding caliper 1012 between an extended position to seal against and hold the sealing body 1010 in place and a retracted position to release hold/seal on the sealing body 1010. The pistons 1104 are configured to apply adequate force to actuate respective ones of the calipers 1012 to seal the sealing body 1010 within a vacuum environment. In some embodiments, four such pistons 1104 are associated with each one of the upper caliper 1012a and lower caliper 1012b. For example, the four pistons 1104 for each of the two calipers 1012 can be disposed at the four upper or lower corners of the interior cavity 1008 of the valve body 1002. Alternatively, there can be more or fewer such pistons 1104 assigned to each caliper 1012, such as 1, 2, 3, 5 or more. In some embodiments, each piston 1104 is pneumatically actuated to translate vertically within a channel defined by a pneumatic plug 1108 secured between a sidewall of the valve body 1002 and one of the internal walls 1106 disposed in the interior cavity 1008 of the valve body 1002. As described above, the internal walls 1106 form a part of the inner chamber 1114 to substantially confine the sealing body 1010 therein, thereby (i) preventing any translative movement of the sealing body 1010 (while facilitating a rotational movement of the sealing body 1010) and (ii) enabling the calipers 1012 to form vacuum seals about the inner chamber 1114. In some embodiments, the pneumatic plug 1108 is secured between a sidewall of the valve body 1002 and an internal wall 1106 by one or more seal sets 1110.

[0134] Furthermore, the section of the sidewall of the valve body 1002 that is adjacent to each piston 1104 can include a set of one or more pneumatic ports 1112 configured to conduct air and/or gas therethrough to actuate the corresponding the piston 1104 and caliper 1012 connected to the piston 1104. For example, for each caliper 1012, the set of pneumatic ports 1112 can include a pneumatic open port 1112a and a pneumatic close port 1112b. In some embodiments, the upper and lower calipers 1012a, 1012b can share one or more pneumatic ports 1112 (e.g., the pneumatic open port 1112a) to ensure synchronized operation of the calipers 1012.

[0135] In operation, to extend a set of calipers 1012 upon activation of a pneumatic signal, air and/or gas can be simultaneously supplied into respective ones of the pneumatic close ports 1112b to translate corresponding pistons 1104 vertically. The vertical, linear movement of the pistons 1104 causes the plates 1011 of the calipers 1012 to travel linearly toward the centroid of the sealing body 1010. The calipers 1012 are configured to have a range of linear motion within the valve body 1002. In some embodiments, each of the

calipers 1012 has a range of linear motion of less than 1 mm. In some embodiments, each of the calipers 1012 has a range of linear motion of about 0.5 mm to about 3 mm. In some embodiments, each of the calipers 1012 has a range of linear motion of about 1mm to about 5 mm, such as about 3 mm to about 5 mm or about 1.25mm or less. The linear movement of the plates 1011 of the calipers 1012 toward the sealing body 1010 in turn causes corresponding mechanical arms 1102a of the plates 1011 to apply compressive force on the sealing body 1010 to retain the sealing body 1010 stationary in either the first (open) position or the second (closed) position. In some embodiments, the compressive force applied by mechanical arms 1102a of the plates 1011 against the surface of the sealing body 1010 enables respective primary seals 1100a secured to the mechanical arms 1102a to physically contact and compress against the outer surface of the sealing body 1010, thereby forming vacuum seals at those interfaces and sealing off the inner chamber 1114.

[0136] The primary seals 1100a ensure that process gas flows through the sealing body 1010 and not the internal cavity 1008 of the valve body 1002, thereby substantially sealing off the valve body 1002 from exposure to corrosive or etchant gasses that travel through the inlet 1004 when the sealing body 1010 is in the first (open) position that enables gas flow, and likewise substantially prevents process gasses from entering the process chamber 106 and any remaining corrosive or etchant gasses of the RPS 104 from entering the valve body 1002 when the seal body 1010 is in the second (closed) position that prevents the flow of gas through the valve body outlet 1006.

[0137] A further advantage of the isolation valve 1000 is that far less of the working surface of each of primary seals 1100a and body seals 1100b is exposed to the flow of corrosive or etchant gasses passing through valve body inlet 1004 as compared to conventional isolation valves, similar to the advantages described above with respect to primary seals 525 of isolation valve 510. For example, configurations of the isolation valve 1000 described herein substantially obscure primary seals 1100a and body seals 1100b from any corrosive or etchant gasses regardless of whether the gas flow path through main channel 1018 is fully open, partially open, or closed, because only a minimal portion of each of primary seals 1100a and body seals 1100b is exposed. In part, this is because primary seals 1100a are compressively sealed against sealing body 1010 and body seals 1100b are compressively sealed against the corresponding portions of the valve body 1002. When these seals 1100 are compressed, there are only small crevices or gaps that are exposed. In

some embodiments, between about 0.5% and about 1% of the surface of each of the seals 1100 is exposed to gasses flowing through the gaps when in a compressed state. In some embodiments, between about 1% and about 5% of the surface of each of the seals 1100 is exposed to gasses flowing through the gaps when in a compressed state. In some embodiments, between about 5% and about 10% of the surface of each of the seals 1100 is exposed to gasses flowing through the gaps when in a compressed state. In general, reducing the exposure of the working surfaces of the seals 1100 can significantly increase their useable life as compared to comparably made sealing elements used in conventional isolation valves.

[0138] To retract the calipers 1012 for releasing the compressive forces applied by the calipers 1012 on the sealing body 1010 upon activation of a pneumatic signal, air and/or gas can be simultaneously supplied into corresponding pneumatic open ports 1112a to translate corresponding pistons 1104 vertically in opposite directions relative to the directions for extending the calipers 1012. The vertical linear movement of the pistons 1104 causes the plates 1011 of the calipers 1012 to travel vertically away from the sealing body 1010, which causes mechanical arms 1102a of the plates 1011 to withdraw from the sealing body 1010 to release it from the stationary sealed position, thereby allowing free rotation of the sealing body 1010 in the inner chamber 1114. More specifically, when the calipers 1012 are retracted, the primary seals 1100a of the calipers 1012 break physical contact with the sealing body 1010 to allow rotation of the sealing body 1010 to the first (open) or second (closed) position. Once the compressive forces applied by the plates 1011 of the calipers 1012 are released, the sealing body 1010 can be rotated to a desired position, after which a pneumatic signal can be activated to repeat the process above to lock the sealing body 1010 in its new position by again actuating the set of calipers 1012 and pistons 1104 described herein. Thus, the calipers 1012 and pistons 1104 can enable sealing (e.g., substantially complete sealing) in both open and closed states of the isolation valve 1000.

[0139] FIGS. 12a and 12b show respective ones of the first (open) position and the second (closed) position of the sealing body 1010 within the internal cavity 1008 of the isolation valve 1000 of FIG. 10, according to embodiments of the technology described herein. As shown, the sealing body 1010 defines a rotational axis 1200 about which the sealing body 1010 rotates within the valve body 1002 to move between the first (open) position and the second (closed) position. In some embodiments, the actuator 1014 is used to control the movement of the sealing body 1010 by applying a rotational force about the

rotational axis 1200 once the calipers 1012 are retracted. As shown in FIGS. 12a and 12b, the actuator 1014 is a dedicated rotary pneumatic actuator that can operate the isolation valve 1000 by pneumatics. Alternatively, the actuator 1014 can be a mechanical or electromechanical actuator that operates the isolation valve 1000 by electric solenoids, for example. The actuator 1014 can be controlled onboard or remotely and can actuate the isolation valve 1000 by means other than pneumatically or electrically to rotate the sealing body 1010 in a prescribed rotation. In some embodiments, the valve body 1002 additionally houses pneumatic and/or electric manifolds and other interlocking components to enable the actuator 1014 to control the movement of the sealing body 1010.

[0140] The sealing body 1010 is rotatable between the first (i.e., open) position, as illustrated in FIG. 12a, and the second (i.e., closed) position, as illustrated in FIG. 12b. More specifically, in the open position, the inlet 1004 of the valve body 1002 is substantially aligned with the first opening 1020 of the central channel 1018 of the sealing body 1010, and the outlet 1006 of the valve body 1002 is substantially aligned with the second opening 1022 of the central channel 1018. This configuration permits gas flow from the inlet 1004 to the outlet 1006 of the valve body 1002 via the central channel 1018 of the sealing body 1010. In the open position, the central channel 1018 is oriented substantially parallel to an axis 1202 extending between the inlet 1004 and the outlet 1006 of the valve body 1002. In the closed position, the sealing areas 1024, 1026 on the surface of the sealing body 1010 are substantially aligned with and provide seals to respective ones of the inlet 1004 and the outlet 1006 of the valve body 1002. The closed position of the sealing body 1010 thus substantially prevents gas flow from the inlet 1004 to the outlet 1006 of the valve body 1002. In the closed position, the central channel 1018 is oriented substantially perpendicular to the axis 1202 extending between the inlet 1004 and the outlet 1006 of the valve body 1002.

[0141] To move the sealing body 1010 between the first and second positions, the actuator 1014 rotates the sealing body 1010 within the interior cavity 1008 of the valve body 1002 about the rotational axis 1200 by a predetermined rotational degree, such as by about 90 degrees. In some embodiments, the channel 1018 can extend along the rotational axis 1200 while the sealing areas 1024, 1026 are located along an axis that is offset from the rotational axis 1200 by a predetermined rotational amount (e.g., 90 degrees). Conversely, the sealing areas 1024, 1026 can extend along the rotational axis 1200 while the channel 1018 extends along an axis that is offset from the rotational axis 1200 by a predetermined rotational

amount. As well understood by a person of ordinary skill in the art, the sealing body 1010, including locations of the channel 1018 and the sealing areas 1024, 1026, can be suitably configured to enable rotation by other amounts about the rotational axis 1200.

[0142] The isolation valve 1000 can have an initial valve state that is either open or closed. In an exemplary operation, assume that the isolation valve 1000 is initially in a closed state (second position), where the central channel 1018 of the sealing body 1010 is about 90 degrees (for example) from the inlet 1004/outlet 1006 of the valve body 1002, as illustrated in FIG. 12b. The calipers 1012 can be extended to lock/seal the sealing body 1010 in place in the closed state. In an exemplary sequence for operating the valve 1000 from the closed state (second position) to an open state (first position), the calipers 1012 are first retracted by moving them from the sealing body 1010, thereby disabling sealed engagement and providing sufficient clearance to rotate the sealing body 1010. Subsequently, the sealing body 1010 is rotated by the actuator 1014 by a prescribed amount to align the channel 1018 with the inlet 1004/outlet 1006. This is followed by activating the calipers 1012 again to move them toward the sealing body 1010 and apply sufficient loading on the seals 1100 to fluidly segregate the valve body 1002 from the sealing body 1010. Finally, the valve 1000 achieves the open state, at which the valve 1000 is ready for full flow operations, as illustrated in FIG. 12a. In some embodiments, this exemplary sequence of motion is reversed to return the valve 1000 from the open state (first position) to the closed state (second position).

[0143] FIG. 13 illustrates a set of exemplary dimensions of the isolation valve 1000 of FIG. 10, according to embodiments of the technology described herein. The height 1302 of the isolation valve 1000 can be between about 1.5 and about 2 times the diameter 1304 of at least one of the inlet 1004 or the outlet 1006 of the valve body 1002. For example, the height 1302 of the isolation valve 1000 can be about 4.3 inches. The length 1306 of the isolation valve 1000, which includes the length of the valve body 1002 and the length of a housing 1308 that houses the rotary actuator 1014, can be about 8.4 inches. The width 1310 of the isolation valve 1000 can be about 5.3 inches. In some embodiments, the valve body 1002 itself can be substantially square in terms of length and width. In some embodiments, due to the construction of the sealing body 1010 as a volumetric element (e.g., sphere), the isolation valve 1000 is much more compact in comparison to the isolation valves described above with reference to FIGS. 3A-7D.

[0144] In some embodiments, the valve body 1002, sealing body 1010 and calipers 1012 are made from a metallic material, such as aluminum or anodized aluminum. In some embodiments, a liner customized to a specific process can be disposed on the wall of the inlet 1004 and/or outlet 1006 the valve body 1002 and/or the wall of the main channel 1018 of the sealing body 1010. The seals 1100 secured to the calipers 1012 can be elastomers. In some embodiments, the isolation valve 1000 includes one or more covers 1312, including an upper cover 1312a and a lower cover 1312b, configured to provide closure to the valve body 1002 and/or other vacuum interfacing features. For example, the upper and lower covers 1312a, 1312b can substantially cover the inlet 1004 and the outlet 1006 of the valve body 1002, respectively.

[0145] In some embodiments, the isolation valve 1000 incorporates thermal management features to prevent overheating due to energy dissipated by chemical processes and to maintain the temperature of the isolation valve 1000 above the condensation point of exposed processes. In some embodiments, such thermal management is passive (e.g., conductive) by means of contact with one or more ported supports. For example, thermal energy from the calipers 1012 can be conducted to the valve body 1002 and the sealing body 1010 when the primary seals 1100a are in a compressed state. Alternatively, such thermal management can be active (e.g., convective) by means of channels disposed within the sealing body 1010 coupled to the ported supports. In some embodiments, the liquid coolant is water, glycol, CDA, dielectric fluorine-based fluid from Galden® or a similar liquid. In some embodiments, heat pipes are incorporated in the components of the isolation valve 1000 for thermal management.

[0146] FIG. 14 shows a cross-sectional view of an exemplary configuration of the valve body 1002 of the isolation valve 1000 of FIG. 10 with integrated cooling features, according to embodiments of the technology described herein. As shown, a thermally managed manifold 1402 can be coupled to the valve body 1002 via one or more sets of dynamic seals 1414. The manifold 1402 can have at least one coolant channel 1404 disposed therein for conducting a coolant therethrough. In some embodiments, at least one section of the manifold 1402, including at a section of the coolant channel 1404, extends into the valve body 1002 and the sealing body 1010 located in the internal cavity 1008 of the valve body

1002. The manifold 1402, however, is separated from the central channel 1018 of the sealing body 1010 so as to segregate the main gas flow 1406 from the coolant flow 1408. During operation, the main gas flow 1406 is adapted to introduce heat flux 1412 to the sealing body 1010 and/or the valve body 1002 via the wall of the central channel 1018. To reduce the heat load and provide heat sinks, the manifold 1402 is thermally managed (e.g., cooled) to provide cooling to the valve body 1002 and the sealing body 1010 via conduction at the thermal interface 1410 between the components. In some embodiments, the coolant flow 1408 within the coolant channel 1404 contributes additional cooling to the valve body 1002 and the sealing body 1010.

[0147] FIG. 15 is a block diagram of a remote plasma source (RPS), such as the RPS 104 of FIG. 2, connected to the isolation valve 1000 of FIG. 10, according to embodiments of the technology described herein. As described above with reference to FIGS. 1A and 1B, the RPS 104 can generate an active gas species for use in a semiconductor fabrication process. The isolation valve 1000, which can be installed downstream from the RPS 104 and upstream from a processing chamber, such as process chamber 106 of FIGS. 1A and 1B, provide a flow path for the reactive gas when isolation valve 1000 is in an open position, and for isolating RPS 104 from the process chamber 106 when the isolation valve 1000 is in a closed position. In addition, as described herein, isolation valve 1000 can include features allowing its valve body 1002 to be purged/reconditioned/passivated with a purge gas supplied by gas distribution (e.g., gas distribution 102 of FIGS. 1A and 1B) and removed from the valve body 1002 via at least one pump (e.g., pump 108 of FIGS. 1A and 1B) installed downstream from the isolation valve 1000 without affecting processes being carried out in the process chamber 106 by bypassing the processing chamber 106. Furthermore, as described herein, the isolation valve 1000 can include features to enable injection of substances downstream of the RPS 104 for enhancing the semiconductor processing operations performed in the process chamber 106 (e.g., described below in relation to FIG. 17).

[0148] In some embodiments, the isolation valve 1000 of FIG. 10 provides similar functions as the isolation valve 110 of FIGS. 1A and 1B and can be integrated with the semiconductor processing system 100a of FIG. 1A or the semiconductor processing system 100b of FIG. 1B in place of the isolation valve 110.

[0149] The next series of drawings illustrate several operational modes of the isolation valve 1000 described herein. These operational modes of the isolation valve 1000 offer similar advantages as the operational modes described above with respect to FIGS. 7A-7D. In some embodiments, the isolation valve 1000 include similar features and operate in similar modes as the valves described above with respect to FIGS. 7A-7D.

[0150] FIG. 16 illustrates another exemplary configuration of the isolation valve 1000 of FIG. 10 with components configured to perform purging of the isolation valve 1000, according to embodiments of the technology described herein. The isolation valve 1000 can include one or more of the elements described above with reference to FIGS. 10-14. As shown in FIG. 16, the sealing body 1010 of the isolation valve 1000 is in the second (closed) position that prevents a flow of gas through the outlet 1006 of the valve body 1002 to a downstream component, such as to the process chamber 106. However, the sealing body 1010 includes at least one bypass port 1602 that provides a flow path from the inlet 1004 of the valve body 1002 (which is in communication with the RPS 104) to at least one outlet aperture 1604 on the valve body 1002. The outlet aperture 1604 is at a different location from the outlet 1006 of the valve body 1002. In some embodiments, the at least one bypass port 1602 is separated from the central channel 1018 of the sealing body 1010. In some embodiment, the at least one bypass port 1602 includes multiple bypass ports disposed in the sealing body 1010 and the at least one outlet aperture 1604 includes multiple outlet apertures disposed on the valve body 1002.

[0151] This configuration of the isolation valve 1000 enables the valve body 1002 and the RPS 104 to be purged simultaneously while other processes (e.g., deposition) are carried out within process chamber 106. For example, a purge gas (e.g., nitrogen, argon) 1600 can be flowed into the interior cavity 1008 of valve body 1002 via the main inlet 1004 of the valve body 1002. The bypass port 1602 then conducts the purge gas from the main inlet 1004 to the outlet aperture 1604, from which substantially all of the purge gas is evacuated using, for example, the pump 108.

[0152] In some embodiments, the central channel 1018 of the sealing body 1010 can also conduct the purge gas received from the main inlet 1004 of the valve body to the outlet aperture 1604 for evacuation from the interior cavity 1008 of the valve body 1002. In some

embodiments, at least one of the bypass port 1602 or the central channel 1018 (e.g., one or both) is utilized to conduct the purge gas to the outlet aperture 1604.

[0153] In some embodiments, the valve body 1002 includes addition apertures, such as aperture 1608, to provide addition purge gas inlet or outlet sites. In some embodiments, at least one of the additional aperture 1608 or the main inlet 1004 (e.g., one or both) is utilized to receive a purge gas into the valve body 1002. In some embodiments, at least one of the additional aperture 1608 or the outlet aperture 1604 (e.g., one or both) is utilized to evacuate the purge gas from the valve body 1002 using the pump 108. In some embodiments, the additional aperture 1608 and outlet aperture 1604 can be formed in top, side, and/or bottom surfaces of the valve body 1002 according to embodiments of the valve technology described herein. In some embodiments, multiple of the additional apertures 1608 and/or the outlet apertures 1604 are formed at various positions in the valve body 1002 and a subset of these apertures can be selectively utilized according to the type of purge process being performed or the area of the interior cavity 1008 the process is intended to purge. In some embodiments, the isolation valve of FIG. 16 can operate in substantially the same fashion as the valve described above with reference to FIG. 7C.

[0154] FIG. 17 illustrates another exemplary configuration of the isolation valve 1000 of FIG. 10 with components configured to perform chemical injection into the isolation valve 1000, according to embodiments of the technology described herein. In this operating mode, the sealing body 1010 is in the first (open) position that enables gas flow from an outlet of the RPS 104 into the inlet 1004 of the valve body 1002, where the gas continues to flow through the central channel 1018 of the sealing body 1010, and subsequently out of the valve body 1002 via the outlet 1006 of the valve body 1002 to the process chamber 106. For example, the flow of gas 1700 from the RPS 104 can be reactive gas species such as atomic fluorine. Additionally, the valve body 1002 can include one or more injection feed channels 1702 in fluid communication with a plenum 1703 in the valve body 1002, both of which are positioned downstream from (e.g., below) the sealing body 1010, such as between the sealing body 1010 and the outlet 1006 of the valve body 1002. The plenum 1703 is in turn in fluid communication with a set of one or more injection holes 1706 located at the outlet 1006 of the valve body 1002. A process or purge gas (e.g., chemical species, forming gas, water vapor) 1704 can be supplied to the injection feed channels 1702, travel through the plenum

1703, and dispensed from the injection holes 1706 for mixture with the main gas flow 1700 as it exits from the central channel 1018.

[0155] In some embodiments, the injection feed channels 1702 and the plenum 1703 can be formed in the sealing body 1010 and in fluid communication with the injection holes 1706 located in the central channel 1018 of the sealing body 1010 to provide the process gas or purge gas 1702 for mixture with the main gas flow 1700 as it travels through the central channel 1018. In some embodiments, the injection feed channels 1702 and plenum 1703 are formed in the valve body 1002 and upstream from (e.g., above) the sealing body 1010, such as between the sealing body 1010 and the inlet 1004 of the valve body 1002, in which case the injection holes 1706 can be located at the inlet 1004 of the valve body 1002. In some embodiments, the isolation valve of FIG. 17 can operate in substantially the same fashion as the valve described above with reference to FIG. 7D.

[0156] FIG. 18 illustrates a flow diagram of a method 1800 for directing an output of a remote plasma source operation through the isolation valve 1000 of FIG. 10, according to embodiments of the technology described therein. Method 1800 includes securing (step 1805) an outlet of the remote plasma source to the inlet 1004 of the valve body 1002 of the isolation valve 1000. For example, as described above with reference to system 100, the outlet of RPS 104 can be mounted directly or adjacent to the valve body inlet 1004.

[0157] Method 1800 also includes, for the isolation valve 1000, rotating (step 1810) the sealing body 1010 within the interior cavity 1008 of the valve body 1002 to achieve the open position of the isolation valve 1000. As described above with reference to FIG. 12a, in the open position, the first opening 1020 and the second opening 1022 of the main channel 1018 of the sealing body 1010 are substantially aligned with corresponding ones of the inlet 1004 and outlet 1006 of the valve body 1002 to permit gas flow through the main channel 1018. More specifically, the open position substantially allows gas flow from the inlet 1004 to the outlet 1006 of the valve body 1002 via the main channel 1018. In some embodiments, the isolation valve 1000 has one or more of (i) features described above with reference to FIG. 16 to present a bypass path to gas flowing from the RPS 104 into the valve inlet 1004 and/or (ii) features described above with reference to FIG. 17 to present injection of additional gases into the main channel 1018.

[0158] Method 1800 additionally includes providing (step 1815) the output of the remote plasma source operation, such as a in the form of a gas flow, to the inlet 1004 of the valve body 1002 via the outlet of the remote plasma source, directing (step 1820) the gas flow from the inlet 1004 of the valve body 1002 to the main channel 1018 disposed in the sealing body 1010 of the valve body 1002, and evacuating (step 1825) the gas flow from the main channel 1018 and the valve body 1002 via the valve body outlet 1006.

[0159] In some embodiments, in the open position of the isolation valve 1000, the output of the remote plasma source operation supplied to the inlet 1004 of the valve 1000 is a reactive species generated by a plasma (e.g., argon plasma, oxygen plasma) formed in the RPS 104. In some embodiments, in the open position of the isolation valve 1000, a reactive gas species from the RPS 104 can be flowed to the process chamber 106 via the central channel 1018 of the valve body 1002. The outlet 1006 of the valve body 1002 of the isolation valve 1000 can be secured to an inlet of the process chamber 106.

[0160] In some embodiments, in the open position of the isolation valve 1000 as illustrated in FIG. 17, one or more chemical species can be injected into the reactive species conducted through the central channel 1018 via one or more of the injection ports 1702 formed in at least one of the sealing body 1010, the valve body 1002 between the sealing body 1010 and the inlet 1004, or the valve body 1002 between the sealing body 1010 and the outlet 1006. Injection of the one or more chemical species while the reactive species flow through the central channel 1018 can enhance or improve the effects of the process.

[0161] In some embodiments, to achieve a closed position of the isolation valve 1000, the sealing body 1010 is rotated within the interior cavity 1008 of the valve body 1002, as described above with reference to FIG. 12b, at which the first sealing surface 1024 the sealing body 1010 is substantially aligned with the inlet 1004 of the valve body 1002, and the second sealing surface 1026 of the sealing body 1010 is substantially aligned with the outlet 1006 of the valve body 1002. This closed position prevents gas flow from the inlet 1004 of the valve body 1002 to the outlet 1006 of the valve body 1002.

[0162] In some embodiments, in the closed position of the isolation valve 1000, the isolation valve 1000 can be purged. For example, a purge operation can be carried out in the RPS 104. RPS supply 112 can supply a purge gas such as argon to a gas inlet of the RPS

104. Referring to FIG. 16, the purge gas 1600 from the RPS 104 can flow into the inlet 1004 of isolation valve body 1002 where bypass port 1602 directs the purging gas 1600 to the interior cavity 1008 of the valve body 1002, which is evacuated via the outlet aperture 1604 that is different from the outlet 1006 of the valve body 1002. In some embodiments, in the closed position, purging can be performed using both the bypass port 1602 and the main channel 1018 of the sealing body 1010, and the purging gas can be evacuated via the outlet aperture 1604 of the valve body 1002.

[0163] Again referring to FIG. 16, in some embodiments, in the closed position of the isolation valve 1000, a purge gas can be supplied to the aperture 1608 of the valve body 1002 and can flow from the aperture 1608 to the outlet aperture 1604 via the bypass port 1602 and/or the main channel 1018 of the valve body 1002. The purge gas can be evacuated from the outlet aperture 1604 by a vacuum created by the pump 108. In some embodiments, at least one of residual gas or particulate matter is also evacuated from the valve body 1002.

[0164] In some embodiments, in the closed position of the isolation valve 1000, the remote plasma source operation and/or evacuation of the output of the remote plasma source operation occurs substantially simultaneously with the purging of the valve body 1002. In some embodiments, in the closed position of the isolation valve 1000, semiconductor processing operations can be performed simultaneously in the process chamber 106 with any of the operations described above.

[0165] FIG. 19 illustrates an exploded view of an exemplary configuration of the isolation valve 1000 of FIG. 10, according to embodiments of the technology described therein. As shown, the valve body 1002 is first provided. The sealing body 1010, such as a spherical body as shown in FIG. 19, is then disposed in the interior cavity 1008 of the valve body 1002. In some embodiments, a set of an upper caliper 1012a and a lower caliper 1012b (collectively referred to as calipers 1012) is provided, where each of the calipers 1012 includes a plate 1011 having two mechanical arms 1102a, 1102b with corresponding ones of the primary seal 1100a and the body seal 1100b secured thereto, as described above with reference to FIG. 11. Each of the upper caliper 1012a and the lower caliper 1012b can be disposed in the interior cavity 1008 of the valve body 1002 above and below the sealing body 1002, respectively. In some embodiments, the upper cover 1312a and the lower cover 1312b

(collectively referred to as covers 1312) are placed on the top and bottom surfaces of the valve body 1002, respectively, to provide protection and interfacing functions.

[0166] In some embodiments, a caliper actuator 1902 can be housed within the valve body 1002 to actuate the movement of the calipers 1012, as described above with reference to FIG. 11. The caliper actuator 1902 can be a pneumatic, electrical or electromechanical actuator. In some embodiments, a set of one or more additional components 1904 can be housed the valve body 1002 to provide structural support, bearing and/or sealing of the sealing body 1010 therein. In some embodiments, a rotary actuator, such as the actuator 1014 described above with respect to FIGS. 12a and 12b, is used to rotate the sealing body 1010 between the open and closed positions about the rotational axis 1200. The rotary actuator 1014 can be stored in the actuator housing 1308 coupled to the valve body 1002. The rotary actuator 1014 can be pneumatically or electrically operated. In some embodiments, an actuator mount 1908 is disposed between the actuator housing 1308 and the valve body 1002 to couple the rotary actuator 1014 to the valve body 1002. In some embodiments, a set of auxiliary components (e.g., a pneumatic manifold) is disposed in the actuator housing 1308, the actuator mount 1908 and/or the valve body 1002 to enable the actuator 1014 to control the movement of the sealing body 1010 within the valve body 1002.

[0167] Variations, modifications, and other implementations of what is described herein will occur to those of ordinary skill in the art without departing from the spirit and the scope of the invention. Accordingly, the invention is not to be limited only to the preceding illustrative descriptions.

What is claimed is:

1. An isolation valve assembly comprising:

a valve body having an inlet and an outlet;

a sealing body disposed within an interior cavity of the valve body, the sealing body comprises a channel extending between a first opening on a surface of the sealing body and a second opening on an opposite surface of the sealing body, the sealing body being rotatable between a first position permitting gas flow from the inlet to the outlet of the valve body via the channel, and a second position preventing gas flow from the inlet to the outlet of the valve body; and

an actuatable closure element disposed within the valve body, the actuatable closure element being configured to retain the sealing body stationary in the first position or the second position.

2. The isolation valve assembly of claim 1, wherein the sealing body is substantially spherical.

3. The isolation valve assembly of claim 1, wherein the sealing body is volumetric with a plurality of facets.

4. The isolation valve assembly of claim 1, wherein, in the first position, the inlet of the valve body is substantially aligned with the first opening of the channel of the sealing body and the outlet of the valve body is substantially aligned with the second opening of the channel of the sealing body.

5. The isolation valve assembly of claim 1, wherein, in the second position, the inlet of the valve body is substantially aligned with a first sealing surface of the sealing body and the outlet of the valve body is substantially aligned with a second sealing surface of the sealing body, the first and second sealing surfaces configured to substantially seal respective ones of the inlet and outlet of the valve body in the second position.

6. The isolation valve assembly of claim 1, wherein, in the second position, the channel is oriented substantially perpendicular to an axis extending between the inlet and the outlet of the valve body.

7. The isolation valve assembly of claim 1, wherein the closure element is further configured to release physical contact with the sealing body when the sealing body is moving between the first and second positions.
8. The isolation valve assembly of claim 1, wherein the closure element is configured to use a compressive force to retain the sealing body stationary in the first position or the second position.
9. The isolation valve assembly of claim 1, further comprising:
 - a first aperture formed in the valve body for receiving a purge gas into the interior cavity of the valve body; and
 - a second aperture formed in the valve body for removing one or more of the purge gas and a residual gas from the interior cavity of the valve body, wherein the second aperture is formed in the valve body at a position remote from the first aperture.
10. The isolation valve assembly of claim 1, wherein the sealing body further comprises at least one bypass channel configured to direct a purge gas from the inlet of the valve body to the interior cavity of the valve body when the sealing body is in the second position.
11. The isolation valve assembly of claim 1, further comprising at least one injection feed channel configured to inject one or more chemical species into the gas flow in the channel when the sealing body is in the first position.
12. The isolation valve assembly of claim 11, wherein the at least one injection feed channel is formed in at least one of the sealing body, the valve body between the sealing body and the inlet, or the valve body between the sealing body and the outlet.
13. The isolation valve assembly of claim 1, further comprising an actuator in electrical or pneumatic communication with the sealing body for rotating the sealing body between the first position and the second position about an axis of rotation.
14. The isolation valve assembly of claim 1, wherein a height of the isolation valve assembly is between about 1.5 and about 2 times the measured diameter of at least one of the inlet or the outlet of the valve body.

15. The isolation valve assembly of claim 1, wherein the closure element comprises at least one O-ring configured to form a seal against an outer surface of the sealing body to retain the sealing body stationary.

16. A method for directing an output of a remote plasma source operation through a valve body of an isolation valve assembly, the method comprising:

- securing an outlet of the remote plasma source to an inlet of the valve body of the isolation valve assembly that includes a rotatable sealing body disposed within an interior cavity of the valve body;

- rotating the sealing body within the interior cavity of the valve body to achieve an open position in which a first opening of a channel of the sealing body is substantially aligned with the inlet of the valve body and a second opening of the channel of the sealing body is substantially aligned with an outlet of the valve body;

- providing the output of the remote plasma source operation to the inlet of the valve body via the outlet of the remote plasma source;

- directing, in the open position, the output from the inlet of the valve body to the channel disposed in the sealing body; and

- evacuating the output of the remote plasma source operation from the channel of the sealing body via the outlet of the valve body.

17. The method of claim 16, further comprising rotating the sealing body within the interior cavity of the valve body to achieve a closed position at which a first sealing surface on the sealing body is substantially aligned with the inlet of the valve body to fluidly seal the inlet, and a second sealing surface on the sealing body is substantially aligned with the outlet of the valve body to fluidly seal the outlet, the closed position preventing gas flow from the inlet of the valve body to the outlet of the valve body.

18. The method of claim 17, further comprising:

- directing, in the closed position, the output from the inlet of the valve body to the interior cavity of the valve body via a bypass channel disposed in the sealing body; and

- evacuating, in the closed position, the output from an outlet aperture disposed in the valve body, wherein the outlet aperture is different from the outlet of the valve body.

19. The method of claim 17, wherein evacuating further comprises simultaneously performing a semiconductor processing operation in a process chamber, wherein the outlet of the valve body of the isolation valve assembly is secured to an inlet of the process chamber.
20. The method of claim 18, wherein the output of the remote plasma source operation comprises one or more of a purge gas from the remote plasma source or a gas generated during a passivation process performed in a chamber of the remote plasma source.
21. The method of claim 16, further comprising flowing, in the open position, a reactive gas species from the remote plasma source to a process chamber via the valve body, wherein the outlet of the valve body of the isolation valve assembly is secured to an inlet of the process chamber.
22. The method of claim 21, further comprising injecting one or more chemical species into the reactive species via one or more injection ports formed in at least one of the sealing body, the valve body between the sealing body and the inlet, or the valve body between the sealing body and the outlet.