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Inventor(s)	Dean; Julian Richard

FLUID ROUTING FOR A VACUUM PUMPING SYSTEM

Abstract

A fluid routing module (**104**) for a vacuum pumping system (**100**), the fluid routing module (**104**) comprising: a first fluid inlet (**110***a*); a first fluid outlet (**114***a*); a first fluid line (**200**) coupled between the first fluid inlet (**110***a*) and the fluid outlet (**114***a*); and a restrictor module (**212**) disposed along the first fluid line (**200**) between the first fluid inlet (**110***a*) and the first fluid outlet (**114***a*), the restrictor module (**212**) being configured to variably restrict a flow of fluid between the first fluid inlet (**110***a*) and the first fluid outlet (**114***a*).

Inventors: **Dean; Julian Richard (Burgess Hill, GB)**

Applicant: **Edwards Limited** (Burgess Hill, GB)

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Background/Summary

[0001] This application is a national stage entry under 35 U.S.C. § 371 of International Application No. PCT/GB2023/050728, filed Mar. 22, 2023, which claims the benefit of GB Application No. 2207187.2, filed May 17, 2022, the entire contents of each of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to fluid routing for use with vacuum pumping systems, including but not limited to vacuum systems for pumping fluids from semiconductor processing tools.

BACKGROUND

[0003] Semiconductor fabrication plants fabricate integrated circuit chips. In the fabrication of such devices, wafers are processed through a number of different processing stations, including stations at which the wafer undergoes, for example, chemical vapor deposition, physical vapor deposition, implant, etch and lithography processes. Many of these processes involve the use of a gaseous ambient and often involve the use of high vacuum and reduced gas pressures.

[0004] Vacuum pumps are used to provide these reduced gas pressures in process chambers, provide chamber evacuation, and maintain flows of processing gases.

SUMMARY

[0005] When the pressure inside a chamber of a semiconductor processing tool is not at working vacuum, for example after a process chamber has been vented to atmospheric pressure to enable service or maintenance, a so-called “pump-down event” is performed to establish the reduced gas pressure in the chamber. A pump-down event involves pumping gas from the chamber so as to reduce the pressure therein to the reduced gas pressure.

[0006] Similarly, when the pressure inside a pumping chamber of a vacuum pump (e.g., a turbopump) is at atmospheric pressure, for example after the vacuum pump has been deactivated to enable service or maintenance, a pump-down event is performed to establish a reduced gas pressure in the pumping chamber of that vacuum pump.

[0007] Vacuum and abatement systems may be used to pump gas from multiple process chambers of a semiconductor processing tool simultaneously using a common pump via a common manifold. The present inventors have realised that in such systems, because multiple chambers and/or multiple turbopumps may be fluidly connected to a common manifold, performing a pump-down event for one of those chambers and/or turbopumps may affect the conditions within others of those chambers. For example, a pump-down event performed on one chamber may cause highly undesirable fluctuations in other chambers connected to the same manifold.

[0008] Aspects of the present disclosure provide a valve module for controlling fluid from multiple chambers of a semiconductor processing tool in such a way that these deficiencies are reduced or eliminated.

[0009] In a first aspect, there is provided a fluid routing module for a vacuum pumping system. The fluid routing module comprises: a first fluid inlet; a first fluid outlet; a first fluid line coupled between the first fluid inlet and the fluid outlet; and a restrictor module disposed along the first fluid line between the first fluid inlet and the first fluid outlet, the restrictor module being configured to variably restrict a flow of fluid between the first fluid inlet and the first fluid outlet.

[0010] The restrictor module may comprise a plurality of restrictors disposed along the first fluid line between the first fluid inlet and the fluid outlet, the plurality of restrictors being arranged in parallel with each other, each restrictor of the plurality of restrictors being configured to restrict a flow of fluid therethrough. The fluid routing module may further comprise means configured to selectably direct a fluid flow through a selected one or more restrictors of the plurality of restrictors while preventing the flow of fluid through the other restrictors of the plurality of restrictors. The means configured to selectably direct a fluid flow through a selected one or more restrictors may comprise a plurality of valves, each valve in the plurality of valves being arranged in series with a respective restrictor of the plurality of restrictors. The fluid routing module may further comprise: a bypass line arranged in parallel with the restrictor module whereby to allow a flow of fluid to bypass the plurality of restrictors; and one or more further valves configured to selectably direct a fluid flow through either the bypass line or the plurality of restrictors. The fluid routing module of may further comprise a valve controller configured to control operation of a valve. Each restrictor of the plurality of restrictors may be configured to restrict a flow of fluid therethrough to a different extent. Each restrictor of the plurality of restrictors may comprise a flow restricting orifice having a different respective diameter.

[0011] The fluid routing module may further comprise a vacuum pump disposed along the first fluid line between the first fluid inlet and the restrictor module. The vacuum pump may be a turbopump.

[0012] The fluid routing module may further comprise: a second fluid inlet; a second fluid outlet; a second fluid line coupled between the second fluid inlet and the fluid outlet; and one or more valves disposed along the second fluid line.

[0013] In a further aspect, there is provided a system comprising: a semiconductor processing tool comprising a processing chamber; the fluid routing module of any preceding aspect, wherein the first fluid inlet is fluidly coupled to the processing chamber; and a vacuum pump operatively coupled to the first fluid outlet.

[0014] The semiconductor processing tool may further comprise one or more further processing chambers. The system may further comprise one or more further fluid routing modules, each further fluid routing module being a fluid routing module in accordance with any preceding aspect, wherein the first fluid inlets of each further fluid routing module are fluidly coupled to a respective further processing chamber. The system may further comprise a fluid line manifold, wherein the first fluid outlets of the fluid routing module and each of the further fluid routing modules are fluidly coupled to the fluid line manifold. The vacuum pump may be operatively coupled to the fluid line manifold.

[0015] The second fluid inlet may be fluidly coupled to the processing chamber. The system may further comprise a further vacuum pump operatively coupled to the second fluid outlet.

[0016] In a further aspect, there is provided a method for routing a fluid through a fluid routing module. The fluid routing module may be in accordance with any preceding aspect. The method comprises: receiving a flow of a fluid at the first fluid inlet; variably restricting, by the restrictor module, the fluid through the restrictor module; and thereafter, the fluid flowing out of the first fluid outlet.

[0017] The fluid routing module may further comprise: a vacuum pump disposed along the first fluid line between the first fluid inlet and the restrictor module; a bypass line arranged to allow a flow of fluid to a flow restricting portion of the restrictor module; and means configured to selectably direct a fluid flow through the bypass line. The method may further comprise, responsive to one or more conditions being satisfied, controlling the further means to cause the fluid to flow through the bypass line, thereby bypassing the flow restricting portion of the restrictor module, The one or more conditions may comprise a condition that a pressure in a pumping chamber of the vacuum pump is below a threshold pressure.

[0018] In any of the above aspects, there may be multiple fluid routing modules, i.e. there may be multiple first fluid inlets, multiple first fluid lines, and multiple first fluid outlets. In addition, there may be a fluid line manifold. The multiple first fluid outlets of the multiple fluid routing modules may be fluidly coupled to the fluid line manifold.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0019] FIG. **1** is a schematic illustration (not to scale) of a semiconductor fabrication facility;

[0020] FIG. **2** is a schematic illustration (not to scale) showing further details of a pumping module of the semiconductor fabrication facility;

[0021] FIG. **3** is a schematic illustration (not to scale) showing further details of a restrictor module of the semiconductor fabrication facility;

[0022] FIG. **4** is a process flow chart showing steps of a process of pumping gas in the semiconductor fabrication facility;

[0023] FIG. **5** is a process flow chart showing steps of a process of operating restrictor valves; and

[0024] FIG. **6** is a schematic illustration (not to scale) illustrating operation of the restrictor valves.

DETAILED DESCRIPTION

[0025] FIG. **1** is a schematic illustration (not to scale) of a semiconductor fabrication facility **100**, in accordance with an example.

[0026] The semiconductor fabrication facility **100** comprises a semiconductor processing tool **102**, a fluid routing module **104**, a first vacuum pump **106**, and a second vacuum pump **107**.

[0027] The semiconductor processing tool **102** comprises a plurality of process chambers **108** in which semiconductor wafers undergo respective processes. Examples of such processes include, but are not limited to, chemical vapor deposition, physical vapor deposition, implant, etch and lithography processes.

[0028] The first vacuum pump **106** is configured to pump fluids (i.e. process gases) out of the process chambers **108** of the semiconductor processing tool **102** via the fluid routing module **104**.

[0029] The second vacuum pump **107** is configured to pump fluids (i.e. process gases) out of the process chambers **108** of the semiconductor processing tool **102** via the fluid routing module **104**.

[0030] The fluid routing module **104** comprises a plurality of fluid inlets (in particular, a plurality of first fluid inlets **110***a* and a plurality of second fluid inlets **110***b*), a plurality of pumping modules **112**, a plurality of fluid outlets (in particular, a plurality of first fluid outlets **114***a* and a plurality of second fluid outlets **114***b*), a first fluid line manifold **116**, and a second fluid line manifold **122**.

[0031] A respective pair of first and second fluid inlets **110***a*, **110***b* is fluidly connected between a respective process chamber **108** and a respective pumping module **112**, such that fluid may flow from that process chamber **108** to that pumping module **112** via either or both of those first and second fluid inlets **110***a*, **110***b*.

[0032] The pumping modules **112** will be described in more detail later below with reference to FIG. **2**.

[0033] Each pumping module **112** is fluidly connected to the first fluid line manifold **116** by a respective first fluid outlet **114***a*, such that fluid may flow from the pumping module **112** to the first fluid line manifold **116**. Each pumping module **112** is fluidly connected to the second fluid line manifold **122** by a respective second fluid outlet **114***b*, such that fluid may flow from the pumping module **112** to the second fluid line manifold **122**.

[0034] The first fluid line manifold **116** is fluidly connected between the plurality of first fluid outlets **114***a* and the first vacuum pump **106**.

[0035] The second fluid line manifold **122** is fluidly connected between the plurality of second fluid outlets **114***b* and the second vacuum pump **107**.

[0036] The fluid routing module **104** further comprises a valve controller **118**.

[0037] The valve controller **118** is operatively coupled, via respective pneumatic lines and/or electrical connections (not shown), to each of a plurality of valves comprised in the pumping modules **112**. These valves are described in more detail later below with reference to FIG. **2**. As described in more detail later below with reference to FIG. **4**, the valve controller **118** is configured to control operation of the valves of the pumping modules **112**, for example by transferring pneumatic fluid thereto via pneumatic lines.

[0038] FIG. **2** is a schematic illustration (not to scale) showing further details of a pumping module **112**. In this example, the pumping modules **112** of the fluid routing module **104** are substantially the same as each other.

[0039] In this example, the first fluid inlet **110***a* and the second fluid inlet **110***b* are fluid inlets of the pumping module **112**. Also, the first fluid outlet **114***a* and the second fluid outlet **114***b* are fluid outlets of the pumping module **112**.

[0040] The pumping module **112** comprises a first fluid line **200** coupled between the first fluid inlet **110***a* and the first fluid outlet **114***a*, and a second fluid line **202** coupled between the second fluid inlet **110***b* and the second fluid outlet **114***b*.

[0041] The pumping module **112** comprises an automatic pressure control (APC) module **208**, a turbopump **210**, a restrictor module **212**, a pressure sensor **214**, and a valve **216**.

[0042] The APC module **208**, the turbopump **210**, the restrictor module **212**, and the pressure sensor **214** are disposed along the first fluid line **200**. The APC module **208** is arranged between the first fluid inlet **110***a* and the turbopump **210**. The turbopump **210** is arranged between the APC module **208** and the restrictor module **212**. The restrictor module **212** is arranged between the turbopump **210** and the pressure sensor **214**. The pressure sensor **214** is arranged between the restrictor module **212** and the first fluid outlet **114***a*.

[0043] The valve **216**, which may be considered to be a chamber roughing valve, is disposed along the second fluid line **202**, and is disposed between the second fluid inlet **110***b* and the second fluid outlet **114***b*.

[0044] The APC module **208** is configured to control a flow of a fluid therethrough. The APC module **208** may comprise a movable valve with a controller. The movable valve of the APC module **208** may comprise a moving pendulum controllable by the controller of the APC module **208** to increase or decrease the size of the orifice in the chamber exhaust path. The APC module **208** may receive a pressure setpoint and an actual pressure reading of the pressure inside the process chamber **108**. The controller of the APC module **208** may then control the pendulum according to a control algorithm until the actual pressure measurement matches the setpoint. In some examples, the valve of the APC module **208** may be controlled by the valve controller **118**.

[0045] The turbopump **210** is coupled to a respective process chamber **108** via the first fluid inlet **110***a*. The turbopump **210** is configured to pump exhaust gases from the process chamber **108**, through the first fluid line **200**, and out of the first fluid outlet **114***a*.

[0046] The restrictor module **212** is described in more detail later below with reference to FIG. **3**.

[0047] The pressure sensor **214** is configured to measure a pressure of the fluid in the first fluid line **200** that is flowing out of the restrictor module **212**. The pressure sensor **214** may be operatively coupled to the valve controller **118** such that pressure measurements taken by the pressure sensor **214** may be received by the valve controller **118**.

[0048] The valve **216** is configured to control a flow of fluid therethrough. In particular, in this example, the valve **216** is configured to be controlled, by the valve controller **118**, to selectably permit or prevent a flow of fluid therethrough.

[0049] FIG. **3** is a schematic illustration (not to scale) showing further details of a restrictor module **212**. In this example, the restrictor modules **212** of the pumping modules **112** are substantially the same as each other.

[0050] The restrictor module **212** comprises a plurality of restrictors. In particular, the restrictor module **212** comprises a first restrictor **301**, a second restrictor **302**, a third restrictor **303**, a fourth restrictor **304**, and a fifth restrictor **305**. The restrictors **301-305** are disposed along the first fluid line **200**. The restrictors **301-305** are arranged in parallel with each other.

[0051] Each restrictor **301-305** is configured to restrict a flow of fluid therethrough. In particular, in this example, each restrictor **301-305** comprises a flow restricting orifice.

[0052] In this example, each restrictor **301-305** is configured to restrict a flow of fluid therethrough to a different extent. Each restrictor **301-305** comprises a flow restricting orifice having a different respective diameter. That is to say, the diameters of the flow restricting orifices of the restrictor **301-305** are different sizes from one another. The diameters of the flow restricting orifices of the restrictors **301-305** may be any appropriate sizes, e.g. sizes selected from a group of values consisting of: 0.5 mm, 0.6 mm, 0.75 mm, 1 mm, and 2 mm. In this example, the first restrictor **301** has a diameter of 0.5 mm, the second restrictor **302** has a diameter of 0.6 mm, the third restrictor **303** has a diameter of 0.75 mm, the fourth restrictor **304** has a diameter of 1 mm, and the fifth restrictor **305** has a diameter of 2 mm.

[0053] The restrictor module **212** further comprises means configured to selectably direct a fluid flow through a selected one or more of the restrictors **301-305** while preventing the flow of fluid through the others of the restrictors **301-305**. In this example, said means for selectably directing fluid flow through a selected one or more of the restrictors **301-305** comprises a plurality of valves, hereinafter called “restrictor valves”. In particular, the restrictor module **212** comprises a first restrictor valve **311**, a second restrictor valve **312**, a third restrictor valve **313**, a fourth restrictor valve **314**, and a fifth restrictor valve **315**. Each restrictor valve **311-315** is fluidly coupled in series with a respective restrictor **301-305**. In particular, the first restrictor valve **311** is connected in series with the first restrictor **301**, the second restrictor valve **312** is connected in series with the second restrictor **302**, the third restrictor valve **313** is connected in series with the third restrictor **303**, the fourth restrictor valve **314** is connected in series with the fourth restrictor **304**, and the fifth restrictor valve **315** is connected in series with the fifth restrictor **305**. The series-connected pairs of restrictors and restrictor valves are connected in parallel with each other.

[0054] Each restrictor valve **311-315** is configured to control a flow of fluid therethrough. In particular, in this example, each restrictor valve **311-315** is configured to be controlled, by the valve controller **118**, to selectably permit or prevent a flow of fluid therethrough. Thus, each restrictor valve **311-315** can selectably allow or prevent fluid flow through the respective restrictor **301-305** coupled in series thereto.

[0055] In this example, the restrictor module **212** further comprises a bypass line **320**. The bypass line **320** is arranged in parallel with the plurality of restrictors **301-305** (and restrictor valves **311-315**). The bypass line **320** is arranged to allow a flow of fluid to bypass the plurality of restrictors **301-305**. The bypass line **320** allows a flow of fluid to avoid the plurality of restrictors **301-305** and flow between the turbopump **210** and the first fluid outlet **114***a* relatively unrestricted.

[0056] In this example, the restrictor module **212** further comprises a valve, hereinafter referred to as a “bypass valve **322**”. The bypass valve **322** is disposed along the bypass line **320**. The bypass valve **322** is configured to control a flow of fluid therethrough. In particular, in this example, the bypass valve **322** is configured to be controlled, by the valve controller **118**, to selectably permit or prevent a flow of fluid therethrough. Thus, the bypass valve **322** can selectably allow or prevent fluid flow through the bypass line **320**.

[0057] The restrictor module **212** may be oriented vertically, i.e. such that process fluid flows though the restrictors in a vertically downwards direction. This orientation and arrangement of the restrictor module **212** tends to prevent blockage of the restrictors **301-305**, for example by liquid, which may flow out of the restrictors **301-305** under gravity.

[0058] Apparatus, including the valve controller **118**, for implementing the above arrangement, and performing the method steps to be described below, may be provided by configuring or adapting any suitable apparatus, for example one or more computers or other processing apparatus or processors, and/or providing additional modules. The apparatus may comprise a computer, a network of computers, or one or more processors, for implementing instructions and using data, including instructions and data in the form of a computer program or plurality of computer programs stored in or on a machine-readable storage medium such as computer memory, a computer disk, ROM, PROM etc., or any combination of these or other storage media.

[0059] The above-described system may undergo a pump-down event to evacuate gas from one or more of the process chambers **108**, which may be at atmospheric pressure, to reduce the pressure therein to a level suitable for a semiconductor fabrication process. The pump-down event may be performed to evacuate gas from a pumping chamber of the turbopump of one or more of the pumping modules.

[0060] What will now be described, with reference to FIGS. **4** to **6**, is a process of pumping gas in the semiconductor fabrication facility **100**, including a pump down event.

[0061] The process steps depicted in the flowcharts of FIGS. **4** and **5** and described below may be omitted or such process steps may be performed in differing order to that presented below and shown in FIGS. **4** and **5**. Furthermore, although the process steps have, for convenience and ease of understanding, been depicted as discrete temporally-sequential steps, nevertheless some of the process steps may in fact be performed simultaneously or at least overlapping to some extent temporally.

[0062] FIG. **4** is a process flow chart showing steps of a process **400** of pumping gas in the semiconductor fabrication facility **100**, including a pump down event.

[0063] At step s**402**, semiconductor fabrication processes are performed in the process chambers **108**. These semiconductor fabrication processes generate process gases.

[0064] In this example, at this stage, for each of the pumping modules **112**, the valves **216** are closed, the restrictor valves **311-315** are closed, and the bypass valves **322** are open. Thus, at step s**402**, the first vacuum pump **106** pumps process gases out of the process chambers **108** through the relatively unrestricted first fluid lines **200** of the pumping modules **112**, and into the first fluid line manifold **116**.

[0065] At step s**404**, one of the process chambers **108** (hereinafter referred to as "the first process chamber **108**" for convenience) is shut down for inspection, servicing, repair, or maintenance. In this example, the shutting down of the first process chamber **108** comprises stopping pumping gas from the first process chamber **108**. In this example, this is achieved by closing the bypass valve **322** of the pumping module **112** associated with the first process chamber **108**. The turbopump **210** of the pumping module **112** associated with the first process chamber **108** is also shut down. In this example, the shutting down the first process chamber **108** further comprises increasing the pressure in the first process chamber **108** to approximately atmospheric pressure. This may be achieved by opening a valve coupled to the first process chamber **108**, thereby allowing air to enter into the first process chamber **108**. In addition, in this example, the pressure in the pumping chamber of the turbopump **210** of the pumping module **112** associated with the first process chamber **108** is also increased to approximately atmospheric pressure.

[0066] At step s**406**, a human operator performs an inspection, servicing, repair, or maintenance operation on the first process chamber **108**. Alternatively, or in addition, inspection, servicing, repair, or maintenance may be performed on one or more components of the pumping module **112** associated with the first process chamber **108**.

[0067] Following the inspection, servicing, repair, or maintenance operation, a low gas pressure environment is to be re-established in the first process chamber **108** such that semiconductor fabrication processes may be performed therein.

[0068] Accordingly, at step s**408**, the valve **216** of the pumping module **112** associated with the first process chamber **108** is opened by the valve controller **118**.

[0069] At step s**410**, with the valve **216** open, the second vacuum pump **107** pumps gases along the second fluid line **202** from the first process chamber **108** into the second fluid line manifold **122**.

[0070] Thus, the first process chamber **108** is "pumped-down". This gas flow from the first process chamber **108** is independent of gas flow through the first fluid line manifold **116**. Advantageously, this separation of flows tends to reduce or eliminate the pumping-down of the first process chamber **108** detrimentally affecting the conditions within parallel process chambers **108**.

[0071] At step s**412**, in response to the pumping down of the first process chamber **108** being completed, the valve controller **118** closes the valve **216** of the pumping module **112** associated with the first process chamber **108**.

[0072] The completion of the pumping down of the first process chamber **108** may be detected by any appropriate means. For example, the valve controller **118** may determine that the pumping-down of the first process chamber **108** is complete in response to a measurement of a pressure within the first process chamber **108** being at or below a first threshold value and/or a calculated rate of decrease of the measured pressure associated with the first process chamber **108** being at or below a second threshold value. The first threshold value may be any appropriate threshold value. The second threshold value may be any appropriate threshold value.

[0073] At step s**414**, in response to the pumping down of the first process chamber **108** being completed, the valve controller **118** controls the restrictors valves **311-315** to open in a predefined sequence. Thus, at step s**414** the restrictor valves **311-315** are open and closed in a predefined pattern.

[0074] In some examples, at step s**414**, the valve controller **118** may also control the APC module **208** to prevent or oppose a flow of fluid therethrough.

[0075] FIG. **5** is a process flow chart showing steps of a process **500** of operating the restrictor valves **311-315**, which may be performed at step s**414**. FIG. **6** is a schematic illustration (not to scale) illustrating operation of the restrictor valves **311-315**. The remaining steps of FIG. **4** will be described in more detail later below after the descriptions of FIGS. **5** and **6**.

[0076] At step s**502**, the first restrictor valve **311** is opened. At step s**502**, the remaining restrictor valves **312-315** and the bypass valve **322** are closed. With the first restrictor valve **311** open, fluid flow is directed through the first restrictor **301**, which in this example has the smallest diameter, that diameter being 0.5 mm. Fluid does not flow through the other restrictors **302-305** or the bypass line **320**. Thus, at step s**502**, the first vacuum pump **106** pumps gases along the first fluid line **200**, from the pumping chamber of the turbopump **210**, into the first fluid line manifold **116**, via the first restrictor **301**.

[0077] At step s**504**, the first restrictor valve **311** is closed and the second restrictor valve **312** is opened. At step s**504**, the first and third through fifth restrictor valves **311**, **313-315** and the bypass valve **322** are closed. With the second restrictor valve **312** open, fluid flow is directed through the second restrictor **302**, which in this example has a diameter larger than the first restrictor **301**, that diameter being 0.6 mm. Fluid does not flow through the other restrictors **301**, **303-305** or the bypass line **320**. Thus, at step s**504**, the first vacuum pump **106** pumps gases along the first fluid line **200**, from the pumping chamber of the turbopump **210**, into the first fluid line manifold **116**, via the second restrictor **302**.

[0078] At step s**506**, the second restrictor valve **312** is closed and the third restrictor valve **313** is opened. At step s**506**, the first, second, fourth, and fifth restrictor valves **311**, **312**, **314**, **315** and the bypass valve **322** are closed. With the third restrictor valve **313** open, fluid flow is directed through the third restrictor **303**, which in this example has a diameter larger than the second restrictor **302**, that diameter being 0.75 mm. Fluid does not flow through the other restrictors **301**, **303**, **304**, **305** or the bypass line **320**. Thus, at step s**506**, the first vacuum pump **106** pumps gases along the first fluid line **200**, from the pumping chamber of the turbopump **210**, into the first fluid line manifold **116**, via the third restrictor **303**.

[0079] At step s**508**, the third restrictor valve **313** is closed and the fourth restrictor valve **314** is opened. At step s**508**, the first through third, and the fifth restrictor valves **311-313**, **315** and the bypass valve **322** are closed. With the fourth restrictor valve **314** open, fluid flow is directed through the fourth restrictor **304**, which in this example has a diameter larger than the third restrictor **303**, that diameter being 1 mm. Fluid does not flow through the other restrictors **301-303**, **305** or the bypass line **320**. Thus, at step s**508**, the first vacuum pump **106** pumps gases along the first fluid line **200**, from the pumping chamber of the turbopump **210**, into the first fluid line manifold **116**, via the fourth restrictor **304**.

[0080] At step s**510**, the fourth restrictor valve **314** is closed and the fifth restrictor valve **315** is opened. At step s**510**, the first through fourth restrictor valves **311-314** and the bypass valve **322** are closed. With the fifth restrictor valve **315** open, fluid flow is directed through the fifth restrictor **305**, which in this example has a diameter larger than the fourth restrictor **304**, that diameter being 2 mm. Fluid does not flow through the other restrictors **301-304** or the bypass line **320**. Thus, at step s**510**, the first vacuum pump **106** pumps gases along the first fluid line **200**, from the pumping chamber of the turbopump **210**, into the first fluid line manifold **116**, via the fifth restrictor **305**.
[0081] FIG. **6** is a schematic illustration (not to scale) showing a graph **600** relating to the process of FIG. **5**.
[0082] The x-axis **602** of the graph **600** is indicative of time, with units in seconds(s).
[0083] The primary y-axis **604** of the graph **600** is indicative of pressure (i.e. pressure in the turbopump), with units in mbar.
[0084] The secondary y-axis **605** of the graph **600** is indicative of gas flow, with units in standard litre per minute (slm).
[0085] The graph **600** comprises two plotted lines, namely a first line **606** and a second line **608**. The first line **606** is solid line. The second line **608** is a dashed line. The first line **606** shows a chamber pressure within the pumping chamber of the turbopump **210**. The second line **608** shows a pressure within a foreline of the pumping system, i.e. within the first fluid inlet **110***a*.
[0086] The x-axis **602** of the graph **600** is portioned or divided into five time intervals, namely a first time interval **611**, a second time interval **612**, a third time interval **613**, a fourth time interval **614**, and a fifth time interval **615**.
[0087] In this example, each time interval is approximately 190 s in duration. However, in other examples, one or more of the time intervals may be a different respective duration other than 190 s.
[0088] The first time interval **611** corresponds to step s**502**. Thus, during the first time interval **611**, the first restrictor valve **311** is open and the other restrictor valves **312-315** and the bypass valve **322** are closed. Thus, fluid flows from the pumping chamber of the turbopump **210** through the first restrictor **301**.
[0089] At the end of the first time interval **611**, the second time interval **612** begins. Also, at the end of the first time interval **611**/the beginning of the second time interval **612**, the first restrictor valve **311** is closed and the second restrictor valve **312** is opened.
[0090] The second time interval **612** corresponds to step s**504**. Thus, during the second time interval **612**, the second restrictor valve **312** is open and the other restrictor valves **311**, **313-315** and the bypass valve **322** are closed. Thus, fluid flows from the pumping chamber of the turbopump **210** through the second restrictor **302**.
[0091] At the end of the second time interval **612**, the third time interval **613** begins. Also, at the end of the second time interval **612**/the beginning of the third time interval **613**, the second restrictor valve **312** is closed and the third restrictor valve **313** is opened.
[0092] The third time interval **613** corresponds to step s**506**. Thus, during the third time interval **613**, the third restrictor valve **313** is open and the other restrictor valves **311**, **312**, **314**, **315** and the bypass valve **322** are closed. Thus, fluid flows from the pumping chamber of the turbopump **210** through the third restrictor **303**.
[0093] At the end of the third time interval **613**, the fourth time interval **614** begins. Also, at the end of the third time interval **613**/beginning of the fourth time interval **614**, the third restrictor valve **313** is closed and the fourth restrictor valve **314** is opened.
[0094] The fourth time interval **614** corresponds to step s**508**. Thus, during the fourth time interval **614**, the fourth restrictor valve **314** is open and the other restrictor valves **311-313**, **315** and the bypass valve **322** are closed. Thus, fluid flows from the pumping chamber of the turbopump **210** through the fourth restrictor **304**.
[0095] At the end of the fourth time interval **614**, the fifth time interval **615** begins. Also, at the end of the fourth time interval **614**/beginning of the fifth time interval **615**, the fourth restrictor valve

314 is closed and the fifth restrictor valve **315** is opened.
[0096] The fifth time interval **615** corresponds to step s**510**. Thus, during the fifth time interval **615**, the fifth restrictor valve **315** is open and the other restrictor valves **311-314** and the bypass valve **322** are closed. Thus, fluid flows from the pumping chamber of the turbopump **210** through the fifth restrictor **305**.
[0097] At the end of the fifth time interval **615**, the fifth restrictor valve **315** is closed.
[0098] At the end of the fifth time interval **615**, the pressure within the pumping chamber of the turbopump **210** tends to less than or equal to a threshold value, e.g. 2 mbar, 3 mbar, 4 mbar, 5 mbar, 6 mbar, 7 mbar, 8 mbar, 9 mbar, or 10 mbar.
[0099] Thus, the pumping chamber of the turbopump **210** is “pumped-down”. This gas flow from the pumping chamber of the turbopump **210** is restricted by, in sequence, the first through fifth restrictors **301-305**. Advantageously, this flow restriction by the restrictors **301-305** tends to reduce or eliminate the pumping-down of the pumping chamber of the turbopump **210** detrimentally affecting the conditions within parallel process chambers **108**. In addition, pumping down the pumping chamber of the turbopump **210** sequentially through restrictors of increasing size advantageously tends to provide for faster pumping down of said pumping chamber, for example, compared to if a single restrictor of fixed size was used.
[0100] In this example, as shown in the graph **600**, the process flow through each chamber **108** is limited to 2 slm (max). This tends to prevent the single vacuum pump being overloaded and unable to provide the vacuum conditions to maintain correct function of the turbo pumps **210**. The restrictors are sized to ensure that a turbo pumpdown from atmosphere never exceeds the chamber flow limit of 2 slm. The restrictors are preferably sized to reduce the pressure as fast as possible. In other examples, a different process flow maximum value, other than 2 slm, may be implemented.
[0101] At the end of the fifth time interval **615**, i.e. after step s**510** the process of FIG. **5**, step s**414** ends, and the process of FIG. **4** proceeds to step s**416**.
[0102] Returning to the description of FIG. **4**, at step s**416**, in response to the pumping down of the pumping chamber of the turbopump **210** being completed, the valve controller **118** controls the fifth restrictor valve **315** to be closed and the bypass valve **322** to be opened. Thus, the flow of fluid is directed through the bypass line **320**, and not through the flow restricting portion **301-305** of the restrictor module **212**.
[0103] In some examples, at step s**416**, the valve controller **118** may also control the APC module **208** to permit a flow of fluid therethrough.
[0104] The completion of the pumping down of the pumping chamber of the turbopump **210** may be detected by any appropriate means. For example, the valve controller **118** may determine that the pumping-down of the pumping chamber of the turbopump **210** is complete in response to a measurement of a pressure within the pumping chamber of the turbopump **210** being at or below a threshold pressure value and/or a calculated rate of decrease of the measured pressure associated with the pumping chamber of the turbopump **210** being at or below a threshold rate value. The threshold pressure value may be any appropriate threshold valve, e.g. 2 mbar, 3 mbar, 4 mbar, 5 mbar, 6 mbar, 7 mbar, 8 mbar, 9 mbar, or 10 mbar. The threshold rate value may be any appropriate threshold valve. The valve controller **118** may determine that the pumping-down of the pumping chamber of the turbopump **210** is complete based on measurements taken by the pressure sensor **214**, and/or any other pressure sensor (e.g. a pressure sensor arranged to measure a pressure within the pumping chamber of the turbopump **210**).
[0105] At step s**418**, following the bypass valve **322** being controlled to direct the flow of fluid through the bypass line **320**, semiconductor fabrication processes may be performed in the first process chamber **108**. These semiconductor fabrication processes generate process gases.
[0106] At step s**420**, the first vacuum pump **106** pumps gases out of the first process chamber **108** through the relatively unrestricted first fluid line **200** of the pumping module **112** associated therewith, and into the first fluid line manifold **116**.

[0107] Thus, a process **400** of pumping gas in the semiconductor fabrication facility **100** is provided.
[0108] The above-described system and method advantageously tends to reduce or eliminate pump-down events detrimentally affecting the conditions within parallel process chambers. This tends to be achieved by pumping pump-down gases via restrictors, i.e. restricted conduits or reduced diameter orifices.
[0109] Advantageously, by pumping pump-down gases via increasing diameter restrictors in sequence, pump down can be performed relatively quickly.
[0110] Advantageously, pump-down events, and the ending of pump-down events, tend to be detected and mitigated against automatically.
[0111] Advantageously, the above-described fluid routing module may be integrated in-line with horizontal manifolds connecting the semiconductor processing tool to the vacuum pumps.
[0112] Advantageously, the above-described fluid routing module tends to be robust. The vacuum module may be fully assembled, leak-checked, and pre-tested, for example, off-site prior to delivery to a semiconductor fabrication facility, or on-site when delivered. This tends to simplify the installation process and reduce installation time.
[0113] Advantageously, the above-described fluid routing module tends to be modular and scalable.
[0114] Advantageously, the components in the gas streams of the fluid routing module tend to be easy to service, repair or replace.
[0115] Advantageously, the status and operating condition of the system tends to be easily monitorable, for example, either via a Human Machine Interface of the valve module or remotely.
[0116] Advantageously, each fluid routing module in a system tends to be easily controllable by a system controller, for example using a communication protocol such as EtherCAT or ethernet.
[0117] Advantageously, the above-described fluid routing module allows for multiple mounting options. For example, the fluid routing module may be suspended from a ceiling of a semiconductor fabrication facility, which provides a benefit of not consuming floor space. Alternatively, the fluid routing module can be mounted in a floor-standing rack or on top of other equipment.
[0118] In the above examples, the fluid routing module is implemented in a semiconductor fabrication facility for routing pumped process gases. However, in other examples, the fluid routing module may be implemented in a different system and be used for routing a different type of fluid.
[0119] In the above examples, there is a single semiconductor processing tool which comprises six process chambers. However, in other examples, there is more than one semiconductor processing tool. One or more of the semiconductor processing tools may comprise a different number of process chambers other than six.
[0120] In the above examples, there is a single fluid routing module comprising six pumping modules. However, in other examples, there may be a different number of fluid routing modules, i.e. multiple fluid routing modules. In some examples, one or more of the fluid routing modules may comprise a different number of pumping modules other than six.
[0121] In the above examples, a pumping module comprises two inlets connected to two outlets. However, in other examples, one or more of the pumping modules comprises a different number of inlets (other than two) and a different number of outlets (other than two). By way of example, a pumping module may comprise two inlets coupled to a single common outlet.
[0122] In the above examples, each pumping module comprises a restrictor module having a plurality of restrictors disposed along the first fluid line between the first fluid inlet and the fluid outlet. The restrictors are arranged in parallel with each other. Thereby, the above-described functionality is provided. However, in other examples, the restrictor module is configured to variably restrict a flow of fluid between the first fluid inlet and the first fluid outlet in a different way. For example, in some examples, the restrictor module comprises one or mare variable restrictors, i.e. one or more restrictors that can each be controlled so as to vary the extent to which

they restrict a flow of a fluid therethrough.

[0123] In the above examples, each restrictor of the plurality of restrictors is coupled in series to a respective restrictor valve. In addition, a bypass valve is arranged in parallel with the restrictor valves. However, in other examples, one or more of the restrictor and/or bypass valves may be replaced by a different arrangement or configuration of valves providing the above-described functionality. For example, in some examples, multiple of the valves (i.e. restrictor valves and/or bypass valve) may be replaced by a multi-way valve disposed at the junction of corresponding fluid lines. This multi-way valve may be configured to direct fluid along a selected one or more of the corresponding fluid lines.

[0124] In the above examples, the pumping chamber of the turbopump is pumped down via the restrictor module. However, in other examples, a different entity (e.g. a process chamber) is pumped down via the restrictor module instead of or in addition to the pumping chamber of the turbopump.

[0125] In the above examples, the pumping chamber of the turbopump is pumped down using restriction orifices of monotonically increasing size. However, in other examples, the restriction orifices are not monotonically increased in size, e.g. restriction orifices may be decreased in size responsive to some criterion being met, such as an effect on a parallel processing chamber.

[0126] In the above examples, the fluid flow is switched between passing through different restrictors responsive to a time interval (e.g., 190 s) elapsing. However, in other examples, the fluid flow is switched between passing through different restrictors in response to a different criterion being met, for example in response to a measured pressure within the pumping chamber, or a rate of change (e.g. decrease) of the measured pressure, meeting a predetermined threshold value. Changeover to larger restrictor sizes can be controlled by time and/or vacuum diagnostics of the turbo pump. An optimisation process may be performed to manage maximum throughput versus minimum time to pump down.

[0127] In some examples, the APC module may be omitted or replaced by one or more valves.

Claims

1. A fluid routing module for a vacuum pumping system, the fluid routing module comprising: a first fluid inlet; a first fluid outlet; a first fluid line coupled between the first fluid inlet and the fluid outlet; and a restrictor module disposed along the first fluid line between the first fluid inlet and the first fluid outlet, the restrictor module being configured to variably restrict a flow of fluid between the first fluid inlet and the first fluid outlet.

2. The fluid routing module of claim 1, wherein: the restrictor module comprises a plurality of restrictors disposed along the first fluid line between the first fluid inlet and the fluid outlet, the plurality of restrictors being arranged in parallel with each other, each restrictor of the plurality of restrictors being configured to restrict a flow of fluid therethrough; and the fluid routing module further comprises means configured to selectably direct a fluid flow through a selected one or more restrictors of the plurality of restrictors while preventing the flow of fluid through the other restrictors of the plurality of restrictors.

3. The fluid routing module of claim 2, wherein the means configured to selectably direct a fluid flow through a selected one or more restrictors comprises a plurality of valves, each valve in the plurality of valves being arranged in series with a respective restrictor of the plurality of restrictors.

4. The fluid routing module of claim 2, further comprising: a bypass line arranged in parallel with the restrictor module whereby to allow a flow of fluid to bypass the plurality of restrictors; and one or more further valves configured to selectably direct a fluid flow through either the bypass line or the plurality of restrictors.

5. The fluid routing module of claim 3, further comprising a valve controller configured to control operation of a valve.

6. The fluid routing module of claim 2, wherein each restrictor of the plurality of restrictors is configured to restrict a flow of fluid therethrough to a different extent.
7. The fluid routing module of claim 6, wherein each restrictor of the plurality of restrictors comprises a flow restricting orifice having a different respective diameter.
8. The fluid routing module of claim 1, further comprising a vacuum pump disposed along the first fluid line between the first fluid inlet and the restrictor module.
9. The fluid routing module of claim 8, wherein the vacuum pump is a turbopump.
10. The fluid routing module of claim 1, further comprising: a second fluid inlet; a second fluid outlet; a second fluid line coupled between the second fluid inlet and the fluid outlet; and one or more valves disposed along the second fluid line.
11. A system comprising: a semiconductor processing tool comprising a processing chamber; the fluid routing module of claim 1, wherein the first fluid inlet is fluidly coupled to the processing chamber; and a vacuum pump operatively coupled to the first fluid outlet.
12. The system of claim 11, wherein: the semiconductor processing tool further comprises one or more further processing chambers; the system further comprises one or more further fluid routing modules, each further fluid routing module being a fluid routing module in accordance with claim 1, wherein the first fluid inlets of each further fluid routing module are fluidly coupled to a respective further processing chamber; the system further comprises a fluid line manifold, wherein the first fluid outlets of the fluid routing module and each of the further fluid routing modules are fluidly coupled to the fluid line manifold; and the vacuum pump is operatively coupled to the fluid line manifold.
13. The system of claim 11, wherein: the fluid routing module is in accordance with claim 10; and the second fluid inlet is fluidly coupled to the processing chamber; and the system further comprises a further vacuum pump operatively coupled to the second fluid outlet.
14. A method for routing a fluid through a fluid routing module, the fluid routing module being in accordance with claim 1, the method comprising: receiving a flow of a fluid at the first fluid inlet; variably restricting, by the restrictor module, the fluid through the restrictor module; and thereafter, the fluid flowing out of the first fluid outlet.
15. The method of claim 14, wherein: the fluid routing module further comprises: a vacuum pump disposed along the first fluid line between the first fluid inlet and the restrictor module; a bypass line arranged to allow a flow of fluid to a flow restricting portion of the restrictor module; and means configured to selectably direct a fluid flow through the bypass line; the method further comprises, responsive to one or more conditions being satisfied, controlling the further means to cause the fluid to flow through the bypass line, thereby bypassing the flow restricting portion of the restrictor module; and the one or more conditions comprises a condition that a pressure in a pumping chamber of the vacuum pump is below a threshold pressure.