METHOD AND APPARATUS FOR PULSE GAS DELIVERY WITH ISOLATION VALVES

RELATED APPLICATION

[0001] This application is a continuation of U.S. Application No. 15/887,447, filed February 2, 2018. The entire teachings of the above application are incorporated herein by reference.

BACKGROUND

[0002] A mass flow controller (MFC) is a device to measure and control the flow of liquids and gases. In general, an MFC includes an inlet port, an outlet port, a mass flow sensor and a proportional control valve that is adjusted to achieve a desired mass flow.

[0003] Semiconductor fabrication processes, such as atomic layer deposition (ALD) processes, can involve the delivery of several different gases and gas mixtures in various quantities over several processing steps. Generally, gases are stored in tanks at a processing facility, and gas metering systems are used to deliver metered quantities of gases from the tanks to processing tools, such as chemical vapor deposition reactors, vacuum sputtering machines, plasma etchers, etc. Typically, components such as valves, pressure regulators, mass flow controller (MFCs), mass flow ratio control systems are included in the gas metering system or in a flow path from the gas metering system to a processing tool.

[0004] Pulse gas delivery devices have been developed to deliver a pulsed mass flow of a gas to semiconductor process tools. High-speed processes can use pulse gas delivery to manufacture advanced, 3-D integrated circuits that include through-silicon vias (TSVs) to provide die-to-die and wafer-to-water interconnects.

SUMMARY

[0004a] Aspects of the present invention are defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

[0005] A disclosed fluid control system for pulse delivery of a fluid includes a flow channel, an isolation valve to initiate and terminate a pulse of fluid from the flow channel, and a pulse mass flow controller (MFC). The MFC includes a control valve to control flow of fluid in the flow channel, a flow sensor to measure flow rate in the flow channel, and a controller to control

flow of fluid through the control valve and switching of the isolation valve, to control a mass of fluid delivered during the pulse of fluid.

[0013] where Δn is the estimated number of moles, Q_m is the measured flow rate by the flow sensor, V_{d2} is the dead volume between the flow restrictor and the isolation valve, P_d is the downstream pressure, t_1 is the start time of the pulse, and t_2 is the stop time of the pulse.

[0014] The flow rate can be measured as a function of the upstream pressure, the downstream pressure, and one or more properties of the fluid, such as molecular weight MW and specific heat ratio γ.

[0015] The system can further include a temperature sensor configured to measure temperature of the fluid in the flow channel, in which case the flow rate can be further measured as a function of the temperature of the fluid.

[0016] The controller can be configured to receive a control signal from a host controller, the control signal including an identification of the fluid, a desired number of moles of the pulse of fluid, a duration of the pulse of fluid, and number of repeated pulses.

[0017] The isolation valve can be integrated into the pulse MFC or can be external to the pulse MFC. For example, the external isolation valve can be a 3-way valve coupled to a process chamber and a dump line. The system can include plural external isolation valves. One of the isolation valves can be coupled to a process chamber and another of the isolation valves can be coupled to a dump line.

[0018] A disclosed method of delivering a pulse of fluid includes controlling flow of fluid into a flow channel with a control valve; measuring flow rate in the flow channel with a flow sensor; controlling switching of an isolation valve to initiate and terminate a pulse of fluid from the flow channel; and controlling flow of fluid through the control valve and switching of the isolation valve to control a mass of fluid delivered during the pulse of fluid.

[0019] Controlling the flow of fluid through the control valve can be based on feedback, e.g. feedback from the flow sensor, during the pulse initiated and terminated by the isolation valve.

[0020] The method can further include detecting an upstream pressure in the flow channel at an upstream position between the control valve and a flow restrictor positioned between the control valve and the isolation valve; and detecting a downstream pressure in the flow channel at a downstream position between the flow restrictor and the isolation valve. Measuring flow rate in the flow channel can be based on the upstream pressure and the downstream pressure.

[0021] The method can further include determining an estimated number of moles of fluid delivered as a function of i) the measured flow rate, ii) the measured pressures, iii) a start time of the pulse of fluid, and iv) a stop time of the pulse of fluid. The flow of fluid through the control valve and the switching of the isolation valve can be controlled based on the estimated number of moles of fluid delivered.

[0022] Implementation of the techniques disclosed herein may provide several advantages. Inclusion of an isolation valve controlled by the MFC, e.g., controller based on estimated number of moles of gas delivered, allows embodiments to speed up the pulse gas delivery, to improve the accuracy of pulse gas delivery, to match the desired pulse shape, to simplify the pulse gas delivery, to save gas usage, to minimize gas species cross contamination in chamber, and to eliminate MFC control valve leak issue. Embodiments of this invention can provide a comprehensive solution for fast pulse delivery applications using mass flow controllers such as ALD and TSV processes.

BRIEF DESCRIPTION OF T HE DRAWINGS

[0023] The foregoing will be apparent from the following more particular description of example embodiments, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments.

[0024] FIG. 1 illustrates a prior pulse gas delivery system using a thermal mass flow controller (MFC) and a divert line.

[0025] FIGs. 2A-2B illustrate a prior pulse gas delivery system employing a fast response MFC.

[0026] FIGs. 3A-3B illustrate a prior pulse gas delivery system using rate of decay pulse delivery.

[0027] FIG. 4 illustrates pulse delivery employing gas dose defined by product of flow set point (Q) and deliver time (Δt).

[0028] FIG. 5 is a schematic illustration of a prior pressure-based pulse MFC device.

[0029] FIG. 6 is a schematic illustration of a pressure-based pulse MFC with an integrated isolation valve.

CLAIMS

What is claimed is:

1. A fluid control system for pulse delivery of a fluid, the system comprising:

a flow channel;

an isolation valve to initiate and terminate a pulse of fluid from the flow channel; and

a mass flow controller (MFC), including a control valve to control flow of fluid in the flow channel, a flow sensor to measure flow rate in the flow channel, and a dedicated controller to control flow of fluid through the control valve based on feedback from the flow sensor, the dedicated controller being arranged for connection to the isolation valve to control switching of the isolation valve to initiate and terminate the pulse, to control a mass of fluid delivered during the pulse of fluid, wherein the dedicated controller is configured to determine an estimated number of moles of fluid delivered as a function of i) the measured flow rate, ii) a start time of the pulse of fluid, and iii) a stop time of the pulse of fluid, and wherein the dedicated controller is configured to control the flow through the control valve and the switching of the isolation valve based on the estimated number of moles of fluid delivered.

2. The system of claim 1, wherein the dedicated controller is configured to control the flow of fluid through the control valve during the pulse initiated and terminated by the isolation valve.

3. The system of claim 1 or claim 2, wherein the flow sensor comprises:

a flow restrictor arranged for disposal within the flow channel and arranged to be positioned between the control valve and the isolation valve;

an upstream pressure sensor configured to detect an upstream pressure in the flow channel at an upstream position between the control valve and the flow restrictor; and

a downstream pressure sensor configured to detect a downstream pressure in the flow channel at a downstream position between the flow restrictor and the isolation valve, the flow sensor being configured to measure flow rate based on the upstream pressure and the downstream pressure.

4. The system of claim 3, wherein the dedicated controller is configured to close the isolation valve based on a computation of the mass of fluid delivered during the pulse of fluid.

5. The system of claim 3, wherein the dedicated controller is configured to determine the estimated number of moles of fluid delivered based on a determination of a residual flow rate and the measured flow rate.

6. The system of claim 5, wherein the dedicated controller is configured to receive an upstream pressure signal corresponding to the upstream pressure and a downstream pressure signal corresponding to the downstream pressure, and to determine the residual flow rate as a function of i) the downstream pressure and ii) a dead volume between the flow restrictor and the isolation valve as

$$(V_{d2} \cdot \frac{\mathrm{d}P_d}{\mathrm{dt}}),$$

where V_{d2} is the dead volume between the flow restrictor and the isolation valve and P_d is the downstream pressure.

7. The system of claim 5 or claim 6, wherein the dedicated controller is configured to determine the estimated number of moles of fluid delivered according to the following equation:

$$\Delta n = \int_{t_1}^{t_2} (Q_m - V_{d2} \cdot \frac{dP_d}{dt}) \cdot dt$$

where Δ_n is the estimated number of moles, Q_m is the measured flow rate by the flow sensor, V_{d2} is the dead volume between the flow restrictor and the isolation valve, P_d is the downstream pressure, t_1 is the start time of the pulse, and t_2 is the stop time of the pulse.

8. The system of any of claims 3 to 7, configured for the flow rate to be measured as a function of the upstream pressure, the downstream pressure, and one or more properties of the fluid.

9. The system of claim 8, wherein the one or more properties of the fluid include molecular weight *MW* and specific heat ratio γ.

10. The system of claim 8, further comprising a temperature sensor configured to measure temperature of the fluid in the flow channel, and further configured for the flow rate to be measured as a function of the temperature of the fluid.

11. The system of any preceding claim, wherein the dedicated controller is configured to receive a control signal from a host controller, the control signal including an identification of the fluid, a desired number of moles of the pulse of fluid, and a duration of the pulse of fluid.

12. The system of claim 1, wherein the isolation valve is integrated into the MFC.

13. The system of claim 1, wherein the isolation valve is external to the MFC.

14. The system of claim 13, wherein the isolation valve is a 3-way valve arranged for coupling to a process chamber and a dump line.

15. The system of claim 13, wherein the system includes plural isolation valves, and wherein one of the isolation valves is arranged for coupling to a process chamber and another of the isolation valves is coupled to a dump line.

16. A method of delivering a pulse of fluid, the method comprising:

controlling flow of fluid into a flow channel with a control valve of a mass flow controller (MFC);

measuring flow rate in the flow channel with a flow sensor of the MFC;

controlling switching of an isolation valve to initiate and terminate a pulse of fluid from the flow channel; and

with a dedicated controller in the MFC, determining an estimated number of moles of fluid delivered, controlling flow of fluid through the control valve based on feedback from the flow sensor, and switching of the isolation valve to control a mass of fluid delivered during the pulse of fluid, wherein the estimated number of moles of fluid delivered is determined as a function of i) the measured flow rate, ii) a start time of the pulse of fluid, and iii) a stop time of the pulse of fluid, and wherein the flow of fluid through the control valve and the switching of the isolation valve are controlled based on the estimated number of moles of fluid delivered.

17. The method of claim 16, wherein controlling the flow of fluid through the control valve is based on feedback from the flow sensor during the pulse initiated and terminated by the isolation valve.

18. The method of claim 16 or claim 17, further comprising:

detecting an upstream pressure in the flow channel at an upstream position between the control valve and a flow restrictor positioned between the control valve and the isolation valve; and

detecting a downstream pressure in the flow channel at a downstream position between the flow restrictor and the isolation valve;

and wherein measuring flow rate in the flow channel is based on the upstream pressure and the downstream pressure.

19. The method of claim 18, further comprising determining a residual flow rate as a function of i) the downstream pressure and ii) the dead volume between the flow restrictor and the isolation valve, and wherein the estimated number of moles of fluid delivered is determined based on the residual flow rate and the measured flow rate.

20. A fluid control system for pulse delivery of a fluid, the system comprising:

a flow channel;

plural isolation valves to initiate and terminate a pulse of fluid from the flow channel, one of the isolation valves being arranged for coupling to a process chamber and another of the isolation valves being arranged for coupling to a dump line; and

a mass flow controller (MFC), including a control valve to control flow of fluid in the flow channel, a flow sensor to measure flow rate in the flow channel, and a dedicated controller to control flow of fluid through the control valve and switching of the isolation valves, to control a mass of fluid delivered during the pulse of fluid.

21. The system of claim 1, wherein the dedicated controller is configured to determine the estimated number of moles of fluid delivered based on a determination of a residual flow rate and the measured flow rate.

22. The method of claim 16, wherein the estimated number of moles of fluid delivered is determined based on a determination of a residual flow rate and the measured flow rate.