APPARATUS AND METHOD FOR MAINTAINING A CONSTANT PRESSURE DROP ACROSS A GAS METERING UNIT

An apparatus is disclosed for maintaining a substantially constant pressure drop across a gas metering unit to ensure precise operation of the unit. The apparatus includes an inlet valve controlling flow to an inlet of the metering unit, an inlet pressure measurement device connected to the inlet of the metering unit, and an outlet pressure measurement device connected to an outlet of the metering unit. The apparatus also includes a controller that receives an actual inlet pressure from the inlet pressure measurement device, receives an actual outlet pressure from the outlet pressure measurement device, compares the actual inlet pressure to the actual outlet pressure to determine an actual pressure change, and causes the inlet valve to vary flow to the inlet of the metering unit if the actual pressure change varies from a predetermined initial pressure change. In this manner the disclosed apparatus maintains a substantially constant pressure drop across the metering unit.
APPARATUS AND METHOD FOR MAINTAINING
A CONSTANT PRESSURE DROP ACROSS A GAS METERING UNIT

Field of Disclosure

The present disclosure relates generally to semiconductor processing equipment and, more particularly, to a flow controller for delivering contaminant-free, precisely metered quantities of process and purge gases to a semiconductor process chamber. Even more particularly, the present disclosure relates to an apparatus and method for maintaining a substantially constant pressure drop across a gas metering unit, such as a flow controller, to ensure precise metering of gases.

Background of Disclosure

The fabrication of a single semiconductor device can require the careful synchronization and precisely measured delivery of as many as a dozen gases to a process chamber. Various recipes are used in the fabrication process, and many discrete processing steps where a semiconductor device is cleaned, polished, oxidized, masked, etched, doped, metalized, etc., may be required. The steps used, their particular sequence and the materials involved all contribute to the making of particular devices.

Accordingly, wafer fabrication facilities are commonly organized to include areas in which chemical vapor deposition, plasma deposition, plasma etching, sputtering and other similar gas manufacturing processes are carried out. The processing tools, be they chemical vapor deposition reactors, vacuum sputtering machines, plasma etchers or plasma enhanced chemical vapor deposition, must be supplied with various process gases. Pure gases must be supplied to the tools in contaminant-free, precisely metered quantities.

In a typical wafer fabrication facility the gases are stored in tanks, which are connected via piping or conduit to a gas box. The gas box delivers contaminant-free, precisely metered quantities of pure inert or reactant gases from the tanks of the fabrication facility to a process tool. The gas box, or gas metering system includes a plurality of gas paths having gas metering units, such as valves, pressure regulators and transducers, mass flow controllers and filters/purifiers. Each gas path has its own inlet for connection to separate sources of gas, but all of the gas paths converge into a single outlet for connection to the process tool.
To insure that precisely metered quantities of gases are delivered to the process tool, there is a need for routine testing of the individual gas paths and metering units of the gas paths. Such testing may comprise flow verification, and a metering unit under test may comprise a mass flow controller, for example. In any event, it is often desired that any pressure drop across a unit under test be constant to ensure accurate test results, correct calibration of the metering unit if necessary, and the precise metering of gases by the unit.

Summary of Disclosure

Accordingly, the present disclosure provides an apparatus for maintaining a substantially constant pressure drop across a gas metering unit to ensure precise metering of gases.

The apparatus includes an inlet valve controlling flow to an inlet of the metering unit, an inlet pressure measurement device connected to the inlet of the metering unit, and an outlet pressure measurement device connected to an outlet of the metering unit. The apparatus also includes a controller that receives an actual inlet pressure from the inlet pressure measurement device, receives an actual outlet pressure from the outlet pressure measurement device, compares the actual inlet pressure to the actual outlet pressure to determine an actual pressure change, and causes the inlet valve to vary flow to the inlet of the metering unit if the actual pressure change varies from a predetermined initial pressure change. In this manner the disclosed apparatus maintains a substantially constant pressure drop across the metering unit.

The present disclosure also provides a gas delivery system including a mass flow controller (MFC) and an apparatus for maintaining a substantially constant pressure drop across the MFC. The disclosure further provides a gas delivery system including an MFC, an apparatus for maintaining a substantially constant pressure drop across the MFC, and a flow verifier for verifying flow through the MFC.

A modular flow verifier incorporating an apparatus according to the present disclosure is disclosed as well. In addition, the present disclosure provides a method of verifying flow through a metering unit under test, wherein the method maintains a substantially constant pressure drop across the metering unit during flow verification.
These and other advantages of the present disclosure will become more apparent to those of ordinary skill in the art after having read the following detailed descriptions of the preferred embodiments, which are illustrated in the attached drawing figures.

**Brief Description of Drawings**

Fig. 1 is a schematic illustration of a gas metering system including a mass flow controller and an apparatus according to the present disclosure for maintaining a substantially constant pressure drop across the mass flow controller;

Fig. 2 is a flow chart illustrating a method according to the present disclosure of maintaining a substantially constant pressure change across a mass flow controller, as carried out by the apparatus of Fig. 1;

Fig. 3 is a schematic illustration of a gas metering system including a mass flow controller, a flow verifier, and an apparatus according to the present disclosure;

Fig. 4 is a schematic illustration of a gas metering system including a mass flow controller, a flow verifier, and another apparatus according to the present disclosure; and

Fig. 5 is a schematic illustration of a gas box system including a plurality of mass flow controllers, a flow verifier, and an apparatus according to the present disclosure.

**Detailed Description of Disclosure**

Referring to Figs. 1 through 5, the present disclosure provides an apparatus and method for maintaining a constant pressure drop across a metering unit. The apparatus and method are particularly for use with gas metering systems for delivering contaminant-free, precisely metered quantities of process and purge gases to a semiconductor process chamber. The presently disclosed apparatus and method ensure precise metering by maintaining a constant pressure drop across the metering unit.
Referring first to Fig. 1, a gas metering system 10 including a metering unit 12 and an apparatus 16 according to the present disclosure are schematically illustrated. As shown, the metering unit can comprise a mass flow controller (MFC) 12, for example.

The gas metering system 10 is connected between a source of gas 90 and a process chamber 92, and a vacuum pump 94 is connected to the process chamber through a gate valve 96. During operation the vacuum pump 94 draws gas from the gas source 90, through the gas metering system 10 and into the process chamber 92. The metering system 10 also includes system valves 20, 22 controlling flow to the process chamber 92 and the vacuum pump 94.

The apparatus 16 for maintaining a constant pressure drop across the MFC 12 includes a controller 40, and an inlet valve 42 controlling flow to an inlet 44 of the MFC 12, a pressure transducer 46 connected to the inlet 44 of the MFC 12, and a pressure transducer 48 connected to an outlet 28 of the MFC 12. Suitable pressure measurement devices for use in the apparatus include Baratron® brand manometers and pressure transducers available from MKS Instruments. Although not shown, it is envisioned that the MFC 12 and the apparatus 16 for maintaining a constant pressure drop across the MFC can be provided as a modular gas path, or stick. Such a modular gas stick would include the MFC 12 and the apparatus 16 mounted on a single gas manifold, for example. Examples of suitable mass flow controllers are MassFlo® brand controllers available from MKS Instruments of Andover, MA (http://www.mkstinst.com).

Referring also to Fig. 2, a method according to the present disclosure of maintaining a substantially constant pressure change across a metering unit, e.g., the MFC 12, as carried out by the controller 40 of the apparatus 16 of Fig. 1, is shown. After being initiated, the controller 40 first calculates an initial pressure change after an initialization period, as shown by "a" through "e" of Fig. 2. As defined herein, the initial pressure change is calculated from initial pressure readings provided by the inlet pressure transducer 46 and the outlet pressure transducer 48. The initial pressure readings can be taken after a suitable initialization period, e.g., 0.5 seconds, after the MFC 12 begins metering gas, to allow MFC pressures to stabilize.

As shown at "f" through "h" of Fig. 2, the controller 40 then receives an actual inlet pressure from the inlet pressure transducer 46, receives an actual outlet pressure from the
outlet pressure transducer 48, and compares the actual inlet pressure to the actual outlet pressure to determine an actual pressure change. If the actual pressure change varies from the predetermined initial pressure change, the controller 40 is programmed to cause the inlet valve 42 to vary flow to the inlet 44 of the MFC 12 until the actual pressure change substantially equals the initial pressure change as shown at "i" through "l" of Fig. 2. In particular, the controller 40 is programmed to cause the inlet valve 42 to decrease flow if the actual pressure change is greater than the initial pressure change, and to increase flow if the actual pressure change is less than the initial pressure change. Flow is increased or decreased until the actual pressure change substantially equals the initial pressure change.

Referring to Fig. 3, another gas metering system 11 is shown. The system 11 of Fig. 3 is similar to the system 10 of Fig. 1, and elements that are the same have the same reference numeral. The system 11 includes the MFC 12, the apparatus 16 according to the present disclosure, and a testing device 14 for testing the MFC 12. The metering system 11 also includes a system valve 18 controlling flow from the source of gas 90.

In the particular embodiment shown, the testing device comprises a flow verifier 14, which verifies flow through the MFC 12. The apparatus 16 maintains a constant pressure drop across the MFC 12 to ensure a precise verification and, if necessary, calibration of the MFC. The verifier 14 includes a vessel 24 having a predetermined volume, a first valve 26 controlling flow between an outlet 28 of the MFC 12 and an inlet 30 of the vessel 24, a second valve 32 controlling flow from an outlet 34 of the vessel 24, and a vessel pressure measurement device 36 communicating with the volume of the vessel.

A controller 38 of the flow verifier 14 utilizes the rate-of-rise method of flow verification. In particular, the controller 38 includes a memory and a clock or timer and is programmed to first close the second valve 32 to stop flow from the outlet 34 of the vessel 24, then open the first valve 26 to allow flow between the outlet 28 of the MFC 12 and the inlet 30 of the vessel 24. As the vessel 24 is filled with gas from the MFC 12, the controller 38 receives measurements of vessel pressure from the measurement device 36, receives measurements of time from its clock, and determines a rate of change in vessel pressure due to the gas flow. The controller 38 then determines an actual flow provided by the MFC 12 using the rate of change in vessel pressure and the known volume of the vessel 24.
Preferably, the flow verifier 14 comprises a GBROR™ in situ flow verifier provided by MKS Instruments of Andover, MA (http://www.mksinst.com). The GBROR™ is a modular gas path, or stick, including the valves, the pressure vessel, the pressure transducer and the controller mounted on a manifold. In addition to being modular, the GBROR™ is process transparent, i.e., operates between the normal processing steps of the gas delivery system and thus reduces processing tool down time.

Referring now to Fig. 4, another apparatus 50 according to the present disclosure for maintaining a substantially constant pressure change across a mass flow controller is shown. The apparatus 50 is operatively connected within a gas delivery system 52 also including a flow verifier 54. The apparatus 50, gas delivery system 52 and flow verifier 54 of Fig. 4 are similar to the apparatus 16, gas delivery system 10 and flow verifier 14 of Fig. 3, and elements that are the same have the same reference numeral.

As is shown in Fig. 4, the apparatus 50 and the flow verifier 54 are preferably incorporated as a combined, in-situ, modular unit 56 having a single controller 58 for controlling both the flow verifier and the apparatus. The unit 56 is preferably connected within the gas delivery system 52 such that the apparatus 50 and flow verifier 54 are process transparent, i.e., operate between normal processing steps such that the unit does not decrease the normal output of a semiconductor processor incorporating the gas delivery system.

The flow verifier 54 includes a by-pass valve 60 for connection between the outlet of the MFC 12 and the vacuum pump 94, which remains open when the verifier is not in use and closes when the verifier is in use. The inlet valve 42 and the inlet pressure transducer 46 of the apparatus 50 are preferably provided as part of a pressure regulator 62 also including a controller 63. A preferred pressure regulator 62 is a Type 640 pressure regulator available from MKS Instruments.

The controller 58 of the combined unit 56 is programmed to determine a desired MFC inlet pressure by adding a difference between the actual pressure drop across the MFC 12 and the initial pressure drop across the MFC 12 to the actual inlet pressure of the MFC. The controller 58 then provides the desired inlet pressure to the controller 63 of the pressure regulator 62, which is programmed to compare the actual inlet pressure to the desired inlet
pressure. If the actual inlet pressure is greater than the desired inlet pressure the controller 63 instructs the inlet valve 42 to reduce flow to the MFC 12 until the actual inlet pressure equals the desired inlet pressure. If the actual inlet pressure is less than the desired inlet pressure the controller 63 instructs the inlet valve 42 to increase flow until the actual inlet pressure equals the desired inlet pressure.

Referring now to Fig. 5, a gas delivery system 64 is shown that incorporates the in-situ, modular, combined unit 54 of Fig. 4. In general, the gas delivery system 64 of Fig. 3 receives multiple gases, including both process gases and a purge gas, from sources 90a, 90b of gas and then precisely meters the gases to the process chamber 92.

The gas delivery system 64 includes gas sticks 66, and each stick includes an MFC 68, a first valve 70 positioned before an inlet 84 to the MFC and a second valve 72 positioned after an outlet 86 of the MFC. The gas sticks 66 are separately connected to the sources 90a of process gas and provide controllable gas passageways so that a contaminant-free, precisely metered amount of a gas, or combination of gases, can be supplied from the gas delivery system to the process chamber 92. Although not shown, the sticks 66 can also each be provided with other components for monitoring or controlling gases, such as filters, purifiers, and pressure transducers and controllers.

The system 64 also includes a first manifold 74 connecting the inlets 84 of the MFCs 68 of the sticks 66, and a second manifold 76 connecting the second valves 72 of the sticks 66. The source 90b of purge gas is connected to the first manifold 74 through a first system valve 78, while the process chamber 92 is connected to the second manifold 76 through a second system valve 80 and the vacuum pump 94 is connected to the second manifold 76 through a third system valve 82. The first manifold 74 selectively provides flow to one of the sticks 66 from the source 90b of purge gas, while the second manifold 76 selectively provides flow from one of the sticks 66 to either the process chamber 92 or the vacuum pump 94. The manifolds 74, 76 can comprise chained pneumatic valves, for example, for selectively providing flow to one of the sticks 66 while isolating the remaining sticks 66.

As shown, the pressure regulator 62 of the unit 56 is connected between the source 90b of purge gas and the first manifold 74, and the by-pass valve 60 of the unit 56 is
connected between the second manifold 76 and the vacuum pump 94. Accordingly, purge gas is used to verify the flow of each gas stick 66 in between normal processing steps. By using the manifolds 74, 76 to provide flow to one stick at a time, the flow verification unit 56 can verify flow and, if necessary, calibrate each of the sticks 66 individually.

While there have been illustrated and described particular embodiments of the present disclosure, it will be appreciated that numerous changes and modifications will occur to those skilled in the art. Accordingly, it is intended that the appended claims cover all those changes and modifications which fall within the true spirit and scope of the present disclosure.
What is claimed is:

1. An apparatus for maintaining a substantially constant pressure drop across a metering unit, comprising:

   a) an inlet valve controlling flow to an inlet of the metering unit;
   b) an inlet pressure measurement device connected to the inlet of the metering unit;
   c) an outlet pressure measurement device connected to an outlet of the metering unit; and
   d) a controller that,

      receives an actual inlet pressure from the inlet pressure measurement device,
      receives an actual outlet pressure from the outlet pressure measurement device,
      compares the actual inlet pressure to the actual outlet pressure to determine an actual pressure change, and
      causes the inlet valve to vary flow to the inlet of the metering unit if the actual pressure change varies from a predetermined initial pressure change.

2. An apparatus according to claim 1 wherein the controller causes:

      the inlet valve to decrease flow if the actual pressure change is greater than the initial pressure change; and
      the inlet valve to increase flow if the actual pressure change is less than the initial pressure change.

3. An apparatus according to claim 1 wherein:

   a) the inlet valve and the inlet pressure measurement device comprise a pressure regulator also including a controller that,
      receives a desired inlet pressure,
      receives the actual inlet pressure from the inlet pressure measurement device,
      compares the actual inlet pressure to the desired inlet pressure,
instructs the inlet valve to reduce flow if the actual inlet pressure is greater than the desired inlet pressure, until the actual inlet pressure equals the desired inlet pressure, and

instructs the inlet valve to increase flow if the actual inlet pressure is less than the desired inlet pressure, until the actual inlet pressure equals the desired inlet pressure; and

b) the controller of the apparatus,
determines a desired inlet pressure by adding to the actual inlet pressure a difference between the actual pressure change and the initial pressure change, and

provides the desired inlet pressure to the controller of the pressure regulator.

4. An apparatus according to claim 1 wherein the controller of the apparatus:
determines a desired inlet pressure by adding to the actual inlet pressure a difference between the actual pressure change and the initial pressure change; and
causes the inlet valve to vary flow until the actual inlet pressure equals the desired inlet pressure.

5. A flow verifier for verifying flow through a metering unit, the flow verifier including an apparatus according to claim 1 and further comprising:
a) a vessel having a predetermined volume;
b) a first valve controlling flow between the outlet of the metering unit and an inlet of the vessel;
c) a second valve controlling flow from an outlet of the vessel;
d) a vessel pressure measurement device communicating with the volume of the vessel;
e) a timer for measuring time;
f) a controller that,
instructs the second valve to stop flow from the outlet of the vessel,
instructs the first valve to allow flow between the outlet of the metering unit and the inlet of the vessel,
receives measurements of vessel pressure from the vessel pressure measurement device,
receives measurements of time from the timer,
determines a rate of change in vessel pressure from the pressure and the time measurements, and
determines an actual flow provided by the metering unit using the rate of change in vessel pressure and the known volume of the vessel.

6. A gas metering flow path including a flow verifier according to claim 5, and further comprising:

   a metering unit having an inlet and an outlet; and
   a main outlet valve for connecting the outlet of the metering unit to a process chamber.

7. A gas metering flow path according to claim 6, wherein the metering unit comprises a mass flow controller.

8. A gas metering system including a flow verifier according to claim 5, and further comprising:

   a plurality of gas metering paths, each path including a potential metering unit having an inlet and an outlet, and a valve for controlling flow from a source of process gas to the inlet of the units; and

   a first manifold connecting the inlets of the units, wherein the inlet valve of the apparatus for maintaining a substantially constant pressure change is connected to the first manifold, the inlet valve for controlling flow from a source of purge gas to the manifold; and

   a second manifold connecting the outlets of the units, wherein the first valve of the flow verifier is connected to the second manifold, the first valve for controlling flow from the second manifold to the vessel of the flow verifier.

9. A gas metering system according to claim 6, wherein the units under test each comprise a mass flow controller.

10. A gas metering flow path for metering gas between a source and a process chamber, comprising:

    a) a mass flow controller for metering gas between a source and a process chamber and having an inlet and an outlet;
b) an apparatus for maintaining a substantially constant pressure drop across the mass flow controller, the apparatus including,
   i) an inlet valve controlling flow from a source of gas to the inlet of the mass flow controller,
   ii) an inlet pressure measurement device connected to the inlet of the mass flow controller,
   iii) an outlet pressure measurement device connected to the outlet of the mass flow controller, and
   iv) a controller that,
   receives an actual inlet pressure from the inlet pressure measurement device,
   receives an actual outlet pressure from the outlet pressure measurement device,
   compares the actual inlet pressure to the actual outlet pressure to determine an actual pressure change, and
   causes the inlet valve to vary flow to the inlet of the mass flow controller if the actual pressure change varies from a predetermined initial pressure change; and
   c) an outlet valve for connecting the outlet of the mass flow controller to a process chamber.

11. A gas metering flow path according to claim 10, wherein the controller causes:
    the inlet valve to decrease flow if the actual pressure change is greater than the initial pressure change; and
    the inlet valve to increase flow if the actual pressure change is less than the initial pressure change.

12. A gas metering flow path according to claim 10, wherein:
   a) the inlet valve and the inlet pressure measurement device comprise a pressure regulator also including a controller that,
   receives a desired inlet pressure,
receives the actual inlet pressure from the inlet pressure measurement device, compares the actual inlet pressure to the desired inlet pressure, instructs the inlet valve to reduce flow if the actual inlet pressure is greater than the desired inlet pressure, until the actual inlet pressure equals the desired inlet pressure, and

instructs the inlet valve to increase flow if the actual inlet pressure is less than the desired inlet pressure, until the actual inlet pressure equals the desired inlet pressure; and

b) the controller of the apparatus for maintaining a substantially constant pressure change,

determines a desired inlet pressure by adding the actual inlet pressure to a difference between the actual pressure change and the initial pressure change, and

provides the desired inlet pressure to the controller of the pressure regulator.

A gas metering flow path according to claim 10 wherein the controller of the apparatus:

determines a desired inlet pressure by adding the actual inlet pressure to a difference between the actual pressure change and the initial pressure change; and

causes the inlet valve to vary flow until the actual inlet pressure equals the desired inlet pressure.

A method of verifying flow through a metering unit comprising:

a) maintaining a substantially constant pressure drop across the metering unit by,

measuring an inlet pressure of the metering unit, measuring an outlet pressure of the metering unit, comparing the inlet pressure to the outlet pressure to determine an actual pressure change between an inlet and an outlet of the metering unit, and

varying flow to the inlet of the metering unit if the actual pressure change varies from a predetermined initial pressure change; and

b) verifying flow through the metering unit by,

directing flow from the outlet of the metering unit into a predetermined volume,

continuously measuring a pressure within the predetermined volume,
measuring a time for the predetermined volume to substantially fill,
determining a rate of change in the pressure of the predetermined volume
based upon the time measurements and a change in the pressure of the predetermined volume, and
determining an actual flow provided by the metering unit based upon the rate of change in vessel pressure and the known volume of the vessel.

15. A method according to claim 14 wherein:
the flow to the inlet of the metering unit is decreased if the actual pressure change between the inlet and the outlet of the metering unit is greater than the initial pressure change; and
the flow to the inlet of the metering unit is increased if the actual pressure change is less than the initial pressure change.

16. A method according to claim 14 further comprising:
determining a desired inlet pressure by adding a difference between the actual pressure change and the initial pressure change to the actual inlet pressure; and
varying flow to the inlet of the metering unit until the actual inlet pressure equals the desired inlet pressure.

17. A method of maintaining a substantially constant pressure drop across a mass flow controller comprising:
measuring an inlet pressure of the mass flow controller;
measuring an outlet pressure of the mass flow controller;
comparing the inlet pressure to the outlet pressure to determine an actual pressure change between an inlet and an outlet of the mass flow controller; and
varying flow to the inlet of the mass flow controller if the actual pressure change varies from a predetermined initial pressure change.

18. A method according to claim 17 wherein:
the flow to the inlet of the mass flow controller is decreased if the actual pressure change between the inlet and the outlet of the mass flow controller is greater than the initial pressure change; and
the flow to the inlet of the mass flow controller is increased if the actual pressure
change is less than the initial pressure change.

19. A method according to claim 17 further comprising:
determining a desired inlet pressure by adding a difference between the actual
pressure change and the initial pressure change to the actual inlet pressure; and
varying flow to the inlet of the mass flow controller until the actual inlet pressure
equals the desired inlet pressure.
Begin Method for Maintaining Constant Pressure Drop Across Metering Unit;

a. Start initialization period count down;

b. Initialization period zero?

Yes

c. Measure inlet pressure of Unit;

d. Measure outlet pressure of Unit;

e. Compute initial pressure change;

f. Measure inlet pressure of Unit;

g. Measure outlet pressure of Unit;

h. Compute actual pressure change;

i. Actual pressure change equal to Initial pressure change?

Yes

Decrease flow to Inlet of Metering Unit;

No

j. Actual pressure change greater than Initial pressure change?

k. Increase flow to Inlet of Metering Unit;

No

FIG. 2