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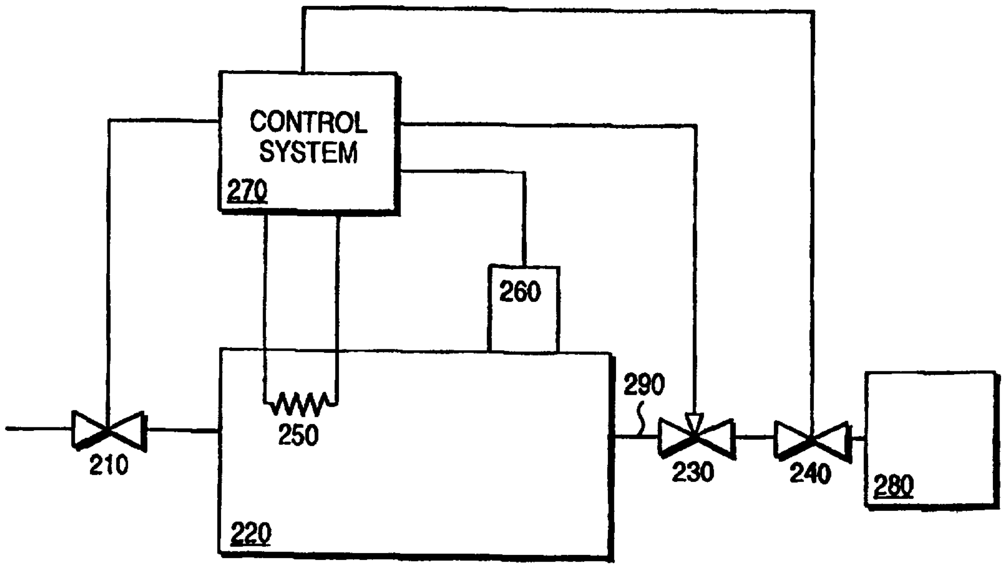

(57) Abstract

A method for injecting a specific mass of gas to a specific point of use location uses a cavity (220) with a known volume which is filled with gas. The temperature and pressure of the gas in the cavity (220) are measured to set the conductivity of a control valve (230) located downstream of the cavity (220), after which the gas is released to the point of use location (280). As the gas is released from the cavity, the temperature and pressure of the gas in the cavity (220) changes. Based on the changes in temperature and pressure, the conductivity of the control valve (230) is adjusted to release the specific mass of the gas to the point of use location (280).

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GAS FLOW CONTROL METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a method for controlling the delivery of a gas to a process chamber. More specifically, the invention relates to a method for injecting a specific mass of gas into a semiconductor process chamber.

2. Background Information

It is known that in many industrial processes it is necessary to control the specific amounts of gas and gas mixtures delivered to point-of-use locations with a high degree of accuracy. Particularly, in semiconductor processing it has become increasingly important to control the specific mass of gases delivered during the fabrication of semiconductor devices. As the speed of next generation semiconductor devices increases and the size/dimension of next generation semiconductor devices decreases the degree of accuracy and control over the fabrication of next generation semiconductor devices must increase. As the architecture of semiconductor devices falls below the submicron scale the semiconductor industry must find more accurate methods for delivering specific amounts of gas to a process chamber. It should be noted, however, that although the use and benefits of the present invention are described in relation to semiconductor processing one with ordinary skill in the art will recognize that such a description is merely illustrative and that the present invention may be applicable in other fields where it is desired to control the specific mass of gas being delivered to a point-of-use location.

One prior art method for delivering a specific mass of gas to a semiconductor process chamber is a Mass Flow Controller. Figure 1 illustrates a prior art Mass Flow Controller (MFC) that is used to control gas flow. The MFC is calibrated to deliver a specific mass of gas to a process chamber within a specified amount of time. For example, an MFC may be calibrated to deliver 100 sccm of nitrogen gas (N_2) to a process chamber.

In order to control the flow of gas the MFC divides the flow of gas between heated sensing tube (sensor) 110 and flow restriction bypass (bypass) 120. The MFC divides the flow of gas such that a majority of the gas flows through bypass 120 and only a small portion of gas flows through sensor 110.

Mass flow is measured in sensor 110. As the gas flow passes through heater coil (coil) 111 the gas picks up and carries heat toward heater coil (coil) 112. The movement of heat by the gas develops a temperature difference between the two coils. Coils 111 and 112 are both heaters but also act as resistance temperature detectors (RTDs) that measure the temperature of the gas. Thus, as the gas flows between coil 111 and coil 112, the change in temperature between coil 111 and coil 112 is measured and can be correlated to the mass flow rate of the gas by the MFC control system 130.

Once the temperature difference is measured and the correlating mass flow rate of the particular gas is determined, control system 130 adjusts the position of control valve 140. The position of control valve 140 is set in order to obtain the desired (or calibrated) flow rate for the particular gas being used.

One problem with the method associated with the MFC for delivering a specific mass of gas to a process chamber is the degree to which the MFC method is accurate. MFC's are currently designed to run at 40 to 80% of their actual calibrated flow rate with an accuracy level of approximately 5%. For example, with respect to the MFC for N_2 calibrated with a flow rate of 100 sccm, described above, that particular MFC is designed to deliver N_2 at flow rates in the range of 40-80 sccm. Outside the 40-80% range the accuracy level of the MFC falls off. Next generation semiconductor devices may require fabrication processes with greater accuracy than the prior art MFCs may be able to provide.

In many applications, it is not desirable to deliver all of the gas for a particular recipe to the process chamber all at once. Likewise it may not be desirable to place a small portion of the gas into the process chamber at the beginning of the process and a larger portion of the gas into the process chamber at the end of the process (or vice versa). Instead it is desirable to deliver the gas to the process chamber at a controlled rate in a manner that optimizes the productivity of that process. Because the accuracy of the MFC decreases outside the 40-80% range of the particular MFC's calibrated flow rate, the degree of control over the delivery of the gas also decreases. Greater control over the delivery of the specific mass of gas is required for next generation semiconductor fabrication processes.

Another example of a method to deliver a specific amount of gas to a point-of-use location within a predetermined amount of time may be seen in the method disclosed in Kennedy, U.S. Pat. No. 4,285,245. Generally speaking, the method disclosed in Kennedy measures the pressure decrease over time of a gas in a chamber in order to maintain the constancy of flow of that gas into a furnace. However, while Kennedy measures the pressure decrease over time, Kennedy assumes that the temperature of the gas remains constant and even takes steps to maintain the temperature of the gas at a constant temperature. In practice, however, the temperature of the gas varies. Therefore, the accuracy maintained with the Kennedy method may fall below that which is desired for next generation semiconductor fabrication processes.

Also, Kennedy measures the pressure of the gas in a chamber which is upstream from a pressure regulator. However, there is gas located within the line that connects the chamber and pressure regulator and there is gas within the regulator itself. The pressure build-up of the gas located in this line and regulator may affect the accuracy with which the gas is delivered. Because Kennedy only measures the pressure of the gas in the chamber and not in the line before the regulator or within the regulator itself, the accuracy maintained with the Kennedy method may be lower than that required by next generation semiconductor fabrication processes.

Additionally, the method described in Kennedy is used for delivering high volumes of gas at high flow rates to a furnace. Using high flow rates to deliver high volumes of gas may decrease the amount of control over the delivery of the gas to the point-of-use location. As described earlier, with respect to MFCs, greater control over the delivery of the specific mass of gas is required for next generation semiconductor fabrication processes.

Thus, what is needed is a method that delivers specific amounts of gases to a processing apparatus with a high degree of accuracy, that does not require a system which is gas sensitive and that delivers the gas to the processing apparatus at a controlled rate for the duration of the particular process.

SUMMARY OF THE INVENTION

An improved method for injecting a specific mass of gas into a process chamber in a predetermined amount of time is disclosed. In one embodiment a cavity with a known volume is filled with a gas. The temperature and pressure of the gas in the cavity are measured to control the conductivity of a valve located downstream of the cavity. Based upon the temperature and pressure measurements the conductivity of the valve is adjusted to release a specific mass of the gas into a process chamber.

In another embodiment where the cavity is not large enough to hold the amount of gas needed for a specific process step, flow-through sampling is utilized. A cavity with a known volume is filled with a gas and the temperature and pressure of the gas in the cavity are measured to determine the initial conductivity of a control valve located downstream of the cavity. The initial conductivity of the control valve is then set and the gas is released from the cavity by opening an outlet isolation valve. As the outlet isolation valve is opened the inlet isolation valve is also cycled such that the cavity is replenished with the gas. The conductivity of the control valve is adjusted throughout this process through the use of sampling. Sampling includes temporarily shutting the inlet isolation valve, measuring the temperature and the pressure of the gas in the cavity, and resetting the conductivity of the control valve based upon the changing temperature and changing pressure. After the desired specific amount of gas is delivered to the process chamber the outlet isolation valve is closed.

Additional embodiments, features, and benefits of the present invention will become apparent from the detailed description, figures, and claims set forth below.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the accompanying figures in which:

Figure 1 illustrates a prior art Mass Flow Controller (MFC) that is used to control gas flow.

Figure 2a illustrates a schematic of one system in which the present invention may be utilized.

Figure 2b illustrates a schematic of another system, the gas multiplexing system, in which the one-volume method of the present invention may be utilized.

Figure 2c illustrates a schematic of another system, the pressure servo system, in which the one-volume and flow-through methods of the present invention may be utilized.

Figure 2d illustrates a schematic of another embodiment of the pressure servo system, in which the one-volume and flow-through methods of the present invention may be utilized.

Figure 3 illustrates a flow chart of one embodiment of the one-volume method of the present invention.

Figure 4 illustrates a flow chart of one embodiment of the multiplexing system of the present invention.

Figure 5 illustrates a flow chart of one embodiment of the flow-through method of the present invention.

Figure 6 graphically illustrates the delivery of an ideal dose of a gas to a process chamber within a predetermined time.

Figure 7 illustrates a flow chart of another embodiment of the flow-through method of the present invention for use with one embodiment of the pressure servo system.

Figure 8 illustrates a flow chart of still another embodiment of the flow-through method of the present invention for use with another embodiment of the pressure servo system.

DETAILED DESCRIPTION

A Gas Flow Control Method is disclosed. In the following description, numerous specific details are set forth such as specific materials, instrumentalities, dimensions, etc. in order to provide a thorough understanding of the present invention. It will be obvious, however, to one skilled in the art that these specific details need not be employed to practice the present invention. In other instances, well known materials or methods have not been described in detail in order to avoid unnecessarily obscuring the present invention. Additionally, it should be noted that although the present invention is described in relation to semiconductor processing one with ordinary skill in the art will recognize that such a description is merely illustrative and is not intended to limit the invention. The specific processes and system described herein are only meant to help clarify one's understanding of the present invention and to illustrate particular embodiments in which the present invention may be implemented. It will be appreciated that the broader spirit and scope of the present invention, as set forth in the appended claims, may be applied to any type of process which seeks the achievements attained by the present invention.

The present invention describes a method for delivering a specific mass of gas within a predetermined amount of time to a point-of-use location, for example a process chamber used for fabricating semiconductor wafers. In semiconductor processing it is desirable to deliver a specific amount (or dose) of gas to the process chamber within a predetermined amount of time. Figure 6 graphically illustrates the delivery of an ideal dose 610 of a gas to a process chamber within a predetermined time, t. Ideally, the flow rate of the gas remains constant over the entire time period, t, such that not all of the gas is delivered to the process chamber all at once or in large bursts. In order to achieve the ideal dose 610 the accuracy of the method with which the gas is delivered must be high. However, as described in the background of the invention, prior art methods for delivering gases are unable to obtain the accuracy levels required by current and future semiconductor processing standards.

Figure 2a illustrates a schematic of one system in which the present invention may be utilized. Figure 3 illustrates a flow chart representing one embodiment of the present invention, the One-Volume Method. Figure 5 illustrates a flow chart representing another embodiment of the present invention, the Flow-Through Method. The discussions of both embodiments illustrated in Figures 3 and 5 below, include references to the schematic shown in Figure 2a in order to further illustrate and clarify the manner in which the embodiments may be implemented. Figures 2b, 2c, and 2d illustrate schematics of three additional systems in which the present invention may be utilized. Figures 4, 7, and 8 illustrate flow charts for the embodiments illustrated in Figures 2b, 2c, and 2d.

One-Volume Method

The One-Volume Method may be utilized in situations where cavity 220 is sufficiently large enough to hold enough gas required for the particular process step being performed at point-of-use location 280. As an example, point-of-use location 280 may be a process chamber that is used in the semiconductor industry for fabricating semiconductor wafers. Figure 3 illustrates a flow chart of one embodiment of the one-volume method of the present invention. At step 310 the one-volume method is begun by filling cavity 220 with a gas. As an example, cavity 220 may be a hollow region within a steel block. Cavity 220, which has a known volume, is filled with a gas by closing outlet isolation valve 240 and opening inlet isolation valve 210. After cavity 220 is filled with gas inlet isolation valve 210 is then closed at step 320.

At step 330, the temperature and pressure of the gas in cavity 220 are measured to determine the mass of the gas within cavity 220. The temperature of the gas in cavity 220 is measured using temperature measuring device 250. In one currently preferred embodiment temperature measuring device 250 is a thermocouple. In another currently preferred embodiment temperature measuring device 250 is a thermister. The pressure of the gas in cavity 220 is measured using pressure transducer 260. In one currently preferred embodiment pressure transducer 260 is a capacitance manometer. It should be noted, and it will be obvious to one with skill in the art, that any device for measuring temperature and any device for measuring pressure may be used in accordance with the concepts of the present invention. It should also be noted, and it will be obvious to one with ordinary skill in the art, that although only a single thermocouple and a single pressure transducer are illustrated in Figure 2, more than one of each may be used in order to determine an average or a mean temperature or pressure of the gas within cavity 220. Additionally, it will also be obvious to one with ordinary skill in the art that, depending upon the size (or dimensions) of cavity 220 the placement or positioning of the thermocouple (or thermocouples) and pressure transducer (or pressure transducers) may vary in order to determine the temperature and pressure of the gas at the center, at the outer edges, etc. of cavity 220.

The temperature and pressure measurements are used by control system 270 to set the initial conductivity of outlet control valve (control valve) 230 at step 340. The conductivity of the control valve is the flow rate of the gas through the control valve. It will be appreciated by one with ordinary skill in the art that as the gas (or fluid) flow resistance of the control valve increases the flow rate of the gas through the control valve will decrease depending upon other parameters such as pressure and temperature (i.e. the changing temperature and/or the changing pressure may affect the amount by which the gas flow resistance and the gas flow rate across/through the control valve increases and decreases, respectively). On the other hand, as the gas flow resistance of the control valve decreases, the flow rate of the gas through the control valve increases. Control system 270 utilizes the ideal gas equation

$$pV=nR_uT,$$

wherein

p = pressure of the gas, V = volume of the cavity
n = the number of moles of gas R_u = constant
T = temperature of the gas

in order to determine the initial conductivity of control valve 230.

It will be obvious to one with ordinary skill in the art, that control system 270 may include an electrical system utilizing conventional switching techniques to operate the equipment in accordance with the methods of the present invention. If desired, the control system may employ conventional solid state microprocessor techniques. If so, it may include items such as an electronic timing device or clock, an analog-to-digital converter, a digital-to-analog converter, output signal amplifiers, storage memory for the control program, an arithmetic unit for calculating the pressure, temperature changes, utilizing the ideal gas equation, and the like. In one currently preferred embodiment control system 270 also includes look-up tables that are used to adjust the control valve 230 based upon the temperature and pressure measurements and the desired conductivity. The look-up tables of control system 270 include all of the calibration values for the desired gases and control valve adjustments that enable control system 270 to establish the initial conductivity of control valve 230 when given the initial pressure and temperature and adjust the conductivity of control valve 230 when given the changing temperature and changing pressure. It will also be obvious to one with ordinary skill in the art, that inlet isolation valve 210 and outlet isolation valve 240 along with control valve 230 may be operated manually, by the same control system, or by different control systems. In one currently preferred embodiment control system 270 operates the inlet and outlet isolation valves 210 and 240, respectively, along with control valve 230.

At step 350, after the initial conductivity of control valve 230 is set, the gas is released from cavity 220 into process chamber 280. Releasing the gas from cavity 220 into process chamber 280 (step 350) includes several "substeps". It should be noted and it will be obvious to one with ordinary skill in the art that although these substeps are numbered and illustrated in a sequential manner (in Figure 3) the sequence of these substeps may be interchanged and/or simultaneously performed.

At substep 351, outlet isolation valve 240 is opened to allow the gas from cavity 220 to flow through line 290 into process chamber 280. At substep 352, as the gas leaves cavity 220, the temperature and pressure of the remaining gas in cavity 220 are measured using thermocouple 250 and capacitance manometer 260, respectively. From these measurements the changing temperature and the changing pressure are calculated by control system 270 and are used to control the conductivity of valve 230 during gas delivery.

Because the present invention takes into account the changing temperature as well as the changing pressure the accuracy with which the present invention delivers a specific mass of gas to the point-of-use location is increased compared to prior art methods. The error for delivering a specific mass of gas into a process chamber may be calculated using the equation

$$\frac{dn}{n} = \frac{dp}{p} + \frac{dV}{V} + \frac{dT}{T}.$$

It is desirable to decrease the error to thereby increase the accuracy of the delivery method.

Prior art methods for delivering a specific mass of gas to a point-of-use location assumed temperature to remain constant or took measures to try to keep the temperature constant. However, by making this assumption the accuracy and the control of these prior art methods are unable to meet the requirements of semiconductor processes.

Other prior art methods (i.e. MFC's) are designed to operate in the range (operation range) of 40-80% of their calibrated flow rates. These methods have an accuracy level of approximately 5% of reading within their operation range. Outside of their operation range the accuracy level of these methods decrease even further. Next generation semiconductor devices require fabrication processes with greater accuracy than these prior art methods. By taking the changing temperature into account, as well as the changing pressure, the present invention has the ability to reach accuracy levels of approximately 1% of reading.

Since the temperature fluctuates and the pressure of the gas in cavity 220 decreases as the gas is released, the flow rate of the gas into process chamber 280 also decreases. Therefore, to control the flow rate and inject the specific mass of gas into process chamber 280 the conductivity of control valve 230 must be adjusted at step 353. Control system 270 calculates the changing temperature and the changing pressure and then adjusts the conductivity of control valve 230 (at substep 353) using the equation

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right)$$

and the look-up tables (as described above) stored within the control system. It should be noted that control valve 230 may be adjusted as many times as needed during the particular process so that the gas is delivered to process chamber 280 with increased accuracy and at a controlled rate.

After the required amount of gas has been injected into process chamber 280, outlet isolation valve 240 is shut, stopping the flow of gas. It should be noted, and it will be obvious to one with skill in the art that outlet isolation valve 240 and outlet control valve 230 may be used interchangeably and may even be one in the same valve. Thus, it will be obvious to one with ordinary skill in the art that the methods of the present invention may be practiced in accordance with the arrangement and type of valves that are used in a particular system.

Figure 2b illustrates a schematic of another system, the gas multiplexing system, in which the one-volume method of the present invention may be used. The gas multiplexing system may be used where the process recipe for a particular process step requires a mixture of gases to be delivered to process chamber 280 using the one-volume method. Three inlet isolation valves 210a, 210b, and 210c are illustrated in Figure 2b. Each of these inlet isolation valves may be used to feed a different gas into cavity 220. Thus, the present invention may be used to create a gas mixture (i.e. multiplexing). For example, a particular process step may require a gas mixture makeup of one-ninth (1/9) of gas-one (G1), three-ninths (3/9) of gas-two (G2), and five-ninths (5/9) of gas-n (Gn).

In order to mix the appropriate amounts of gas with high accuracy a multiplexing process as illustrated in Figure 4 may be used. At step 410, outlet isolation valve 240 is closed. At step 411, the inlet isolation valve for one of the gases is opened, for example, inlet isolation valve 210a is opened for Gas-1 (G1). The temperature and pressure of the gas in cavity 220 are then measured using thermocouple 250 and capacitance manometer 260, respectively. The temperature and pressure measurements are then used by control system 270 to calculate the mass of gas in cavity 220, at step 412. Once the desired amount of Gas-1 is determined to be in cavity 220 then, at step 413, inlet isolation valve 210a is closed (or shut off). Next, at step 421, the inlet isolation valve for another one of the gases needed for the particular gas mixture is opened, for example, inlet isolation valve 210b is opened for Gas-2 (G2). The temperature and pressure of the gas in cavity 220 are then measured using thermocouple 250 and capacitance manometer 260, respectively. The temperature and pressure measurements are then used by control system 270 to calculate the mass of gas in cavity 220, at step 422. From such calculations the amount of Gas-2 and the amount of Gas-1 that are in cavity 220 may be determined. When the desired amount of Gas-2 is determined to be in cavity 220, inlet isolation valve 210b is shut off (closed), at step 423.

The above described process may be continued for any desired number of gases, for example, Gas-1, Gas-2, . . .Gas-n (G1, G2, . . . Gn). For each Gas-n, the inlet isolation valve for that Gas-n is opened (at step 491), the temperature and pressure of the gas in cavity 220 are measured (at step 492), and the inlet isolation valve for Gas-n is shut-off when the desired amount of Gas-n is determined to be in cavity 220.

Cavity 220 is then filled, using the above described multiplexing method, with the appropriate amount of each gas to create the desired gas ratio (e.g. 1/9 G1, 3/9 G2, and 5/9 G3) and the one-volume method as described above may be used to deliver the gas mixture to process chamber 280. It will be obvious to one with ordinary skill in the art that, although three gases are illustrated in Figure 2b, any number of gases (greater than, less than, or equal to three) may be multiplexed with the present invention. It will also be obvious to one with ordinary skill in the art that control system 270 may be designed to mix the gases to any desired ratios. It should be noted and it will be obvious to one with ordinary skill in the art that, all or only some of the gases connected to the cavity may be used to form several different gas mixtures. For example, in Figure 2c, gas mixtures may be made of: Gas-1 and Gas-2; Gas-1 and Gas-n; Gas-2 and Gas-n; Gas-1, Gas-2 and Gas-n; and so on, for as many gases as are connected to the cavity.

Flow-Through Method

The Flow-Through Method may be utilized in situations where cavity 220 is not sufficiently large enough to hold the required amount of gas for the particular process step being performed at point-of-use location 280. Figure 5 illustrates a flow chart of one embodiment of the flow-through method of the present invention. It should be noted that many of the steps of the flow-through method are similar to those of the one-volume method described above, however, they are repeated (briefly) in the following discussion of Figure 5 (i.e. the flow-through method) for clarity. For example, steps 310-340 of the one-volume method, and steps 510-540 of the flow-through method are similar. It should also be noted that the following discussion of the flow-through method and Figure 5 also refers to the system illustrated in Figure 2a, unless stated otherwise.

At step 510 the flow-through method is begun by filling cavity 220 with a gas. Cavity 220, which has a known volume, is filled with a gas by closing outlet isolation valve 240 and opening inlet isolation valve 210. After cavity 220 is filled with gas, inlet isolation valve 210 is then closed at step 520. At step 530, the temperature and pressure of the gas in cavity 220 are measured in order to determine the mass of the gas in the cavity. The temperature of the gas in cavity 220 is measured using thermocouple (or thermister) 250. The pressure of the gas in cavity 220 is measured using capacitance manometer 260. The temperature and pressure measurements are used by control system 270 to set the initial conductivity of outlet control valve (control valve) 230 at step 540. Control system 270, as described above in the discussion of the one-volume method, utilizes the ideal gas equation

$$pV=nR_uT$$

in order to determine the initial conductivity of control valve 230.

At step 550, after the initial conductivity of control valve 230 is set, the gas is released from cavity 220 into process chamber 280. Releasing the gas from cavity 220 into process chamber 280 (step 550) includes substeps 551 and 552. Because this is a flow-through method (i.e. the process being performed in process chamber 280 requires a greater mass of gas than cavity 220 is able to hold and still achieve the desired flow rate) both outlet isolation valve 240 and inlet isolation valve 210 are opened. It should be noted and it will be obvious to one with ordinary skill in the art that although these substeps are numbered and illustrated in a sequential manner (in Figure 5) the sequence of these substeps may be interchanged and/or simultaneously performed. In one currently preferred embodiment outlet isolation valve 240 and inlet isolation valve 210 are opened simultaneously in order to replenish the gas supply in cavity 220.

At substep 551, outlet isolation valve 240 is opened to allow the gas from cavity 220 to flow through line 290 into process chamber 280. At substep 552 inlet isolation valve 210 is also opened in order to allow more gas to enter cavity 220 thereby replenishing the supply of gas within cavity 220. As some of the gas leaves and more gas enters cavity 220, the temperature and pressure of the gas remaining in cavity 220 may change.

Due to the changing temperature and changing pressure of the gas in cavity 220, as in the one-volume method described above, the conductivity of control valve 230 may be adjusted in order to inject the specific mass of gas with greater accuracy and at a controlled flow rate. However, in order to adjust the conductivity of control valve 230 and maintain the desired accuracy the changing temperature and changing pressure must be measured. In one currently preferred embodiment the changing temperature and changing pressure of the gas in cavity 220 are measured by "sampling". Sampling is performed by temporarily closing inlet isolation valve 210, quickly taking temperature and pressure measurements, and then reopening inlet isolation valve 210.

The conductivity of control valve 230 is adjusted at step 560. Step 560 includes substeps 561-564. At substep 561, inlet isolation valve 210 is temporarily shut. At substep 562, the temperature and pressure of the gas in cavity 220 are measured and the changing temperature and the changing pressure are calculated by control system 270. Because the present invention takes into account the changing temperature as well as the changing pressure the accuracy with which the present invention delivers a specific mass of gas to the point-of-use location is increased compared to prior art methods.

Control system 270 calculates the changing temperature and the changing pressure and then adjusts the conductivity of control valve 230 using the equation

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right)$$

and the look-up tables stored within the control system. At substep 563, the conductivity of control valve 230 is reset and, at substep 564, inlet isolation valve 210 is reopened. It should be noted that, control valve 230 may be adjusted as many times as needed during the specified period of time required to release the gas for a particular process so that the gas is delivered to process chamber 280 with greater accuracy and at a controlled rate.

After the required amount of gas has been injected into process chamber 280, outlet isolation valve 240 is shut, at step 570, stopping the flow of gas. It should be noted and it will be obvious to one with ordinary skill in the art that, after the required amount of gas is delivered to process chamber 280 using the flow-through method, inlet isolation valve 210 may also be shut so that cavity 220 will no longer fill up with gas. It will also be obvious to one with ordinary skill in the art that inlet isolation valve 210 may be shut prior to the completion of the particular process being performed in process chamber 280, should it be determined that cavity 220 holds enough gas to complete the process step using the one-volume method described above.

An advantage to the flow-through method, rather than increasing the volume of cavity 220 by using higher pressures, is that the higher the pressure of the gas in cavity 220 the lower the accuracy in metering the discreet amounts of the gas into process chamber 280. If a particular process step requires, for example, three (3) liters of gas, and cavity 220 has a capacity of only one-half (0.5) liter, then to fill cavity 220 with the necessary 3 liters would require the cavity to be filled to a pressure of approximately 100psi. However, some gases cannot be delivered at a controlled rate at such pressures, thereby diminishing the accuracy with which the gas is injected into process chamber 280. The flow-through method allows a process to be supplied with larger quantities of gas while the pressure of the gas in cavity 220 is held at lower pressures in order to increase the control and the accuracy with which the gas is injected into process chamber 280.

Figure 2c illustrates a schematic of another system, the pressure servo system, in which the one-volume and flow-through methods, described above, may be used. The pressure servo system may be used to stabilize the flow rate of the gas that is being delivered to process chamber 280 using the one-volume method or flow-through method. In the pressure servo system shown in Figure 2c a second pressure transducer 265 and a fixed orifice 266 are added to the system of Figure 2a. Pressure transducer 265 is positioned downstream of control valve 230 and upstream of fixed orifice 266. In one currently preferred embodiment pressure transducer 265 is a capacitance manometer. However, as noted above with respect to pressure transducer

260, pressure transducer 265 may be any device with which the pressure of the gas may be measured.

Pressure transducer 265 measures the pressure of the gas at a point downstream of control valve 230 and upstream of fixed orifice 266. Based upon the pressure measurement of pressure transducer 265 and assuming the temperature of the gas to be constant, control system 270 utilizes the ideal gas equation, as previously described, to calculate the instantaneous flow rate of the gas coming out of control valve 230.

Figure 7 illustrates a flow chart of the flow-through method for the pressure servo system illustrated in Figure 2c. It should be noted that many of the steps of the flow-through method using the pressure servo system of Figure 2c are similar to those of the flow-through method described in the discussion of Figure 5 above, and are therefore not repeated in detail. For example, steps 510-552 of the flow-through method in Figure 5 are the same as steps 710-752 of the flow-through method using pressure servo system in Figure 7.

In the pressure servo system illustrated in Figure 2c, the initial conductivity of control valve 230 is set (at step 740) using the temperature and pressure measurements of the gas in cavity 220 taken using thermocouple 250 and capacitance manometer 260, respectively. When the gas in cavity 220 is released (i.e., when gas flow is begun) the conductivity of outlet control valve 230 is adjusted based on the instantaneous flow rate that is calculated using the pressure measurements of capacitance manometer 265.

As with the embodiment of the flow-through method previously described in the discussion of Figure 5, "Sampling" is used to measure the changing pressure and thereby determining the changing instantaneous flow rate. At substep 761, inlet isolation valve 210 is temporarily shut. Pressure measurements are then quickly taken using capacitance manometer 265 which is downstream of control valve 230 and upstream of fixed orifice 266, at substep 762. The instantaneous flow rate is then calculated using the pressure measurements by control system 270 and, based upon the changing instantaneous flow rate, the conductivity of control valve 230 is reset (or adjusted) at substep 763. Then at substep 764, inlet isolation valve 210 is reopened. Because the pressure servo system of the present invention takes into account the temperature and pressure of the gas in the cavity when determining the initial conductivity of the control valve, and because the pressure servo system adjusts the conductivity based upon pressure measurements (i.e., the instantaneous flow rates) downstream of the control valve, the accuracy with which the present invention delivers a specific mass of gas to the point-of-use location is increased compared to prior art methods.

Control system 270 calculates the changing instantaneous flow rate and then adjusts the conductivity of control valve 230 using the equation

$$\Delta n = \frac{V}{RT}(p_1 - p_2)$$

and the lookup tables stored within the control system. It should be noted that in the pressure servo system when adjusting the conductivity of the control valve, temperature is assumed to be constant, however, greater accuracy than the prior art methods is still achieved because the instantaneous flow rate is being determined at a point downstream of the control valve. Thus, the changing pressure in the cavity, in the line, and in the control valve are all being accounted for in the pressure servo system of the present invention, thereby providing greater accuracy.

It should be noted that the pressure servo system described above (i.e. Figure 2c) may also be used in conjunction with the one-volume method of the present invention. Rather than adjusting the conductivity of the control valve (at step 353 of the one-volume method illustrated in Figure 3) based upon the changing temperature and changing pressure of the gas in the cavity (which is measured at step 352), the conductivity of the control valve is adjusted based upon the instantaneous flow rate. The instantaneous flow rate is calculated by measuring the changing pressure of the gas near the fixed orifice and then using those pressure measurements in the ideal gas equation, as previously described. It should also be noted that, although it is not illustrated in the figures, pressure transducer 265 may also be added to the gas multiplexing system of Figure 2b to achieve similar results.

Figure 8 illustrates a flow chart of the flow-through method for another embodiment of the pressure servo system illustrated in Figure 2d. It should be noted that most of the steps of the flow-through method using the pressure servo system of Figure 2d are similar to those of the flow-through method using the pressure servo system of Figure 2c which is described in the discussion of Figure 7 above, and are therefore not repeated herein. For example, steps 710- 720 and 740-770 of Figure 7 are similar to steps 810-820 and 840-870 of Figure 8.

In the pressure servo system illustrated in Figure 2d, only a single pressure transducer 265 is used. Pressure transducer 265 is positioned downstream of control valve 230 and upstream of fixed orifice 266. Thus, in order to set the initial conductivity of control valve 230, the temperature of the gas in the cavity is measured using thermocouple 250 and the pressure of the gas is measured using capacitance manometer 265 at a point downstream of control valve 230 and upstream of fixed orifice 266, at step 840. Control system 270 then sets the initial conductivity of the control valve 230, at step 840, based upon these temperature and pressure measurements utilizing the ideal gas equation and lookup tables as described above with reference to steps 730 and 740 of Figure 7. The method then continues with steps 850-870 as described above in the description of steps 750-770 of Figure 7.

It should be noted that in the embodiment of the pressure servo system illustrated in Figure 2d, because the changing pressure in the cavity, in the line, and in the control valve are taken into account when setting the initial conductivity of the control valve and when adjusting the conductivity of the control valve, the accuracy with which a specific mass of gas is being delivered to the point-of-use location is greater than in prior art methods. Also, it should be noted that since only a single capacitance manometer 265 is used, the cost of the system may lower than in other systems.

Further, it should be noted that the pressure servo system illustrated in Figure 2d of the present invention may also be used in conjunction with the one-volume method of the present invention. At step 330, of the one-volume method (illustrated in Figure 3), in order to use the pressure servo system of Figure 2d, the temperature of the gas should be measured using thermocouple 250 and the pressure of the gas should be measured at a point downstream of control valve 230 and upstream of fixed orifice 266 using capacitance manometer 265. Then at step 340, the initial conductivity of the one-volume method is set using these temperature and pressure measurements. At steps 352 and 353, the conductivity of control valve 230 is adjusted based upon the changing instantaneous flow rate as described above in conjunction with the use of the one-volume method with the pressure servo system of Figure 2c.

Additionally, it should be noted and it will be obvious to one with ordinary skill in the art that, with reference to any of the embodiments of the flow-through method of the present invention described above that the inlet isolation valve may be shut prior to the completion of the particular process step being performed in process chamber 280, should it be determined that cavity 220 holds enough gas to complete the process using one of the embodiments of the one-volume method described above.

Furthermore, it should be noted and it will be obvious to one with ordinary skill in the art that, with reference to any of the embodiments of the one-volume method of the present invention described above that the multiplexing process (illustrated in Figure 4) and the multiplexing system (illustrated in Figure 2b) may be used in conjunction therewith.

With respect to both the one-volume method and flow-through method, and any embodiments thereof, it should be noted that after outlet isolation valve 240 is shut and the specified mass of gas has been delivered to the process chamber, the pressure and temperature of the remaining gas in cavity 220 may again be measured, in order to correct for future processing steps. For example, if two process steps to be performed in process chamber 280 require the same type of gas, and the first process step is completed, the temperature and pressure of the remaining gas in cavity 220 may be measured to determine the amount of gas remaining in cavity 220. If enough gas remains to perform the second process step, then the temperature and pressure measurements may be used to configure the system (i.e. reset control valve 230) so that the gas may be delivered as accurately in the second process step as it was delivered in the first process step. If there is not enough gas to perform the second process step, then the pressure and temperature measurements may be used to determine how much additional gas is required to complete the second process step.

Additionally, with respect to both the one-volume method and flow-through method, and any embodiments thereof, it should be noted that, although not shown in any of the system configurations 2a-2d, the present invention may be equipped with a pump-purge system, so that the remaining gas in cavity 220 after a particular process step may be removed (i.e. pumped and purged from the cavity). Pump-purging cavity 220 allows the same cavity to be used for many different gases and gas mixtures. Thus, the system of the present invention is not gas specific, thereby allowing the system of the present invention to be calibrated for many types of gases, a benefit that was not available in prior art MFCs.

Thus, a Gas Flow Control Method has been described. Although specific embodiments, including specific equipment, parameters, and methods have been described, various modifications to the disclosed embodiments will be apparent to one of ordinary skill in the art upon reading this disclosure. Therefore, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention and that this invention is not limited to the specific embodiments shown and described.

CLAIMS

What is claimed is:

1. A method for injecting a specific mass of gas into a process chamber, said method comprising the steps of:

filling a cavity having a known volume with said gas;

measuring the pressure and temperature of said gas within said cavity; and

adjusting the conductivity of a valve located downstream of said cavity to release said specific mass of gas into said process chamber within a predetermined amount of time based upon said pressure and temperature measurements.

2. The method as recited in claim 1 wherein a control system is used to adjust the conductivity of said valve in accordance with the following function:

$$pV=nR_uT.$$

3. The method as recited in claim 1 wherein a closed loop control system is used to adjust the conductivity of said valve in accordance with the following function:

$$pV=nR_uT.$$

4. The method as recited in claim 1 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

5. The method as recited in claim 1 wherein the pressure of said gas is measured using a capacitance manometer.

6. The method as recited in claims 4 or 5 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system controlling the conductivity of said valve based upon a changing temperature and said changing pressure of said gas in said cavity in accordance with the following function:

$$pV=nR_uT.$$

7. The method as recited in claim 1 wherein said gas is a gas mixture.

8. The method as recited in claim 7 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

9. A method for injecting a specific mass of gas into a process chamber, said method comprising the steps of:

filling a cavity having a known volume with said gas;

measuring the pressure and temperature of said gas within said cavity to determine the mass of said gas in said cavity; and

controlling the conductivity of a valve located downstream of said cavity to release said specific mass of gas into said process chamber within a predetermined amount of time based upon a changing pressure and a changing temperature of said gas in said cavity.

10. The method as recited in claim 9 wherein a control system is used to adjust the conductivity of said valve in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

11. The method as recited in claim 9 wherein a closed loop control system is used to adjust the conductivity of said valve in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

12. The method as recited in claim 9 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

13. The method as recited in claim 9 wherein the pressure of said gas is measured using a capacitance manometer.

14. The method as recited in claims 12 or 13 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system controlling said conductivity of said valve based upon said changing temperature and said changing pressure of said gas in said cavity in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

15. The method as recited in claim 9 wherein said gas is a gas mixture.

16. The method as recited in claim 15 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

17. A method for delivering a specific mass of gas into a process chamber comprising the steps of:

filling a cavity with a gas, wherein said cavity has a known volume, an inlet isolation valve, an outlet control valve, and an outlet isolation valve and wherein said step of filling said cavity is performed while said inlet isolation valve is open and said outlet isolation valve is closed;

closing said inlet isolation valve of said cavity after said filling step;

measuring the temperature and pressure of said gas in said cavity to determine the mass of said gas in said cavity;

determining the initial conductivity of said outlet control valve required to release said specific mass of gas into said process chamber; setting the initial conductivity of said outlet control valve;

releasing said specific mass of gas from said cavity into said process chamber, wherein said step of releasing said gas includes:

opening said outlet isolation valve;

measuring a changing pressure and a changing temperature of said gas in said cavity in order to control the conductivity of said outlet control valve;

adjusting the conductivity of said outlet control valve such that said specific mass of gas is released within a predetermined amount of time based upon the changing pressure and the changing temperature; and

shutting said outlet isolation valve after said specific mass of gas is released into said process chamber.

18. The method as cited in claim 17 further comprising the step of:

measuring the temperature and pressure of said gas in order to correct for future processing steps, wherein said step of measuring the temperature and pressure of said gas is performed after said step of shutting said outlet isolation valve and after said specific mass of gas is released into said process chamber.

19. The method as recited in claim 17 wherein a control system is used to adjust the conductivity of said outlet control valve in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

20. The method as recited in claim 17 wherein a closed loop control system is used to adjust the conductivity of said outlet control valve in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

21. The method as recited in claim 17 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

22. The method as recited in claim 17 wherein the pressure of said gas is measured using a capacitance manometer.

23. The method as recited in claims 21 or 22 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system controlling the conductivity of said outlet control valve based upon said changing temperature and said changing pressure of said gas in said cavity in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

24. The method as recited in claim 17 wherein said gas is a gas mixture.

25. The method as recited in claim 24 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

26. A method for injecting a specific mass of gas into a process chamber, said method comprising the steps of:

filling a cavity with a gas, wherein said cavity has a known volume, an inlet isolation valve, an outlet control valve, and an outlet isolation valve and wherein said step of filling said cavity is performed while said inlet isolation valve is open and said outlet isolation valve is closed;

closing said inlet isolation valve of said cavity after said filling step;

measuring the temperature and pressure of said gas in said cavity to set the initial conductivity of said outlet control valve required to release said specific mass of gas into said process chamber;
setting the initial conductivity of said outlet control valve;

releasing said gas into said process chamber, wherein said step of releasing said gas includes:
opening said outlet isolation valve; and
opening said inlet isolation valve;

adjusting the conductivity of said outlet control valve such that said specific mass of gas is released within a predetermined amount of time, wherein said step of adjusting the conductivity of said outlet control valve includes:

temporarily shutting said inlet isolation valve;

measuring the changing pressure and changing temperature of said gas in said cavity in order control the conductivity size of said outlet control valve;

resetting the conductivity of said outlet control valve based upon the changing pressure and the changing temperature;

reopening said inlet isolation valve; and

shutting said outlet isolation valve after said specific mass of gas is released into said process chamber.

27. The method as cited in claim 26 further comprising the step of:

measuring the temperature and pressure of said gas in order to correct for future processing steps, wherein said step of measuring the temperature and pressure of said gas is performed after said step of shutting said outlet isolation valve and after said specific mass of gas is released into said process chamber.

28. The method as recited in claim 26 further comprising the steps of:

determining if said cavity contains enough of said gas to complete the delivery of said specific mass of said gas; and

shutting said inlet isolation valve after it has been determined that said cavity contains enough of said gas to complete the delivery of said specific mass of said gas.

29. The method as recited in claim 26 wherein a control system is used to adjust the conductivity of said outlet control valve in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

30. The method as recited in claim 26 wherein a closed loop control system is used to adjust the conductivity of said outlet control valve in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

31. The method as recited in claim 26 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

32. The method as recited in claim 26 wherein the pressure of said gas is measured using a capacitance manometer.

33. The method as recited in claims 31 or 32 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system controlling the conductivity of said outlet control valve based upon said changing temperature and said

changing pressure of said gas in said cavity in accordance with the following function:

$$\Delta n = \frac{V}{R}\left(\frac{p_1}{T_1} - \frac{p_2}{T_2}\right).$$

34. The method as recited in claim 26 wherein said gas is a gas mixture.

35. The method as recited in claim 34 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

36. A method for delivering a specific mass of gas into a process chamber at a stable flow rate comprising the steps of:

filling a cavity with a gas, wherein said cavity has a known volume, an inlet isolation valve, an outlet control valve, and an outlet isolation valve and wherein said step of filling said cavity is performed while said inlet isolation valve is open and said outlet isolation valve is closed;

closing said inlet isolation valve of said cavity after said filling step;

measuring the temperature and pressure of said gas in said cavity to determine the mass of said gas in said cavity;

determining the initial conductivity of said outlet control valve required to release said specific mass of gas into said process chamber based upon said temperature and pressure measurements of said gas in said cavity;

setting the initial conductivity of said outlet control valve;

releasing said specific mass of gas from said cavity into said process chamber, wherein said step of releasing said gas includes:

opening said outlet isolation valve;

measuring the pressure of said gas at a point located downstream of said outlet control valve and upstream of a fixed orifice to determine an instantaneous flow rate of said outlet control valve in order to control the conductivity of said outlet control valve;

adjusting the conductivity of said outlet control valve such that said specific mass of gas is released within a predetermined amount of time based upon said instantaneous flow rate; and

shutting said outlet isolation valve after said specific mass of gas is released into said process chamber.

37. The method as cited in claim 36 further comprising the step of:

measuring the temperature and pressure of said gas in order to correct for future processing steps, wherein said step of measuring the temperature and pressure of said gas is performed after said step of shutting said outlet isolation valve and after said specific mass of gas is released into said process chamber.

38. The method as recited in claim 36 wherein a control system is used to determine the initial conductivity of said outlet control valve which is based upon the pressure and the temperature of said gas in said cavity in accordance with the following function:

$$pV=nR_uT.$$

39. The method as recited in claim 36 wherein a control system is used to adjust the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

40. The method as recited in claim 36 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

41. The method as recited in claim 36 wherein the pressure of said gas is measured using a capacitance manometer.

42. The method as recited in claims 40 or 41 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system determining the initial conductivity of said outlet control valve which is based upon the pressure and the temperature of said gas in said cavity in accordance with the following function:

$$pV = nR_uT.$$

43. The method as recited in claims 40 or 41 wherein a computer system having a timer is coupled to said capacitance manometer, said computer system controlling the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

44. The method as recited in claim 36 wherein said gas is a gas mixture.

45. The method as recited in claim 44 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

46. A method for injecting a specific mass of gas into a process chamber at a stable flow rate, said method comprising the steps of:

filling a cavity with a gas, wherein said cavity has a known volume, an inlet isolation valve, an outlet control valve, and an outlet isolation valve and wherein said step of filling said cavity is performed while said inlet isolation valve is open and said outlet isolation valve is closed;

closing said inlet isolation valve of said cavity after said filling step;

measuring the temperature and pressure of said gas in said cavity to determine the mass of said gas in said cavity and to set the initial conductivity of said outlet control valve required to release said specific mass of gas into said process chamber;

setting the initial conductivity of said outlet control valve;

releasing said gas into said process chamber, wherein said step of releasing said gas includes:

opening said outlet isolation valve; and

opening said inlet isolation valve;

adjusting the conductivity of said outlet control valve based upon an instantaneous flow rate such that said specific mass of gas is released within a predetermined amount of time, wherein said step of adjusting the conductivity of said outlet control valve includes:

temporarily shutting said inlet isolation valve;

measuring the pressure of said gas at a point located downstream of said outlet control valve and upstream of a fixed orifice to determine said instantaneous flow rate of said outlet control valve in order to control the conductivity of said outlet control valve;

resetting the conductivity of said outlet control valve based upon said instantaneous flow rate;

reopening said inlet isolation valve; and

shutting said outlet isolation valve after said specific mass of gas is released into said process chamber.

47. The method as cited in claim 46 further comprising the step of:

measuring the temperature and pressure of said gas in order to correct for future processing steps, wherein said step of measuring the temperature and pressure of said gas is performed after said step of shutting said outlet isolation valve and after said specific mass of gas is released into said process chamber.

48. The method as recited in claim 46 further comprising the steps of:

determining if said cavity contains enough of said gas to complete the delivery of said specific mass of said gas; and

shutting said inlet isolation valve after it has been determined that said cavity contains enough of said gas to complete the delivery of said specific mass of said gas.

49. The method as recited in claim 46 wherein a control system is used to determine the initial conductivity of said outlet control valve which is based upon the pressure and the temperature of said gas in said cavity in accordance with the following function:

$$pV=nR_uT.$$

50. The method as recited in claim 46 wherein a control system is used to adjust the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

51. The method as recited in claim 46 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

52. The method as recited in claim 46 wherein the pressure of said gas is measured using a capacitance manometer.

53. The method as recited in claims 51 or 52 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system determining the initial conductivity of said outlet control valve based upon the pressure and temperature of said gas in said cavity in accordance with the following function:

$$pV=nR_uT.$$

54. The method as recited in claims 51 or 52 wherein a computer system having a timer is coupled to said capacitance manometer, said computer system controlling the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

55. The method as recited in claim 46 wherein said gas is a gas mixture.

56. The method as recited in claim 55 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

57. A method for delivering a specific mass of gas into a process chamber at a stable flow rate comprising the steps of:

filling a cavity with a gas, wherein said cavity has a known volume, an inlet isolation valve, an outlet control valve, and an outlet isolation valve and wherein said step of filling said cavity is performed while said inlet isolation valve is open and said outlet isolation valve is closed;

closing said inlet isolation valve of said cavity after said filling step;

measuring the temperature of said gas in said cavity and measuring the pressure of said gas at a point downstream of said outlet control valve and upstream of a fixed orifice to determine the mass of said gas;

determining the initial conductivity of said outlet control valve required to release said specific mass of gas into said process chamber based upon said temperature and pressure measurements of said gas;

setting the initial conductivity of said outlet control valve;

releasing said specific mass of gas from said cavity into said process chamber, wherein said step of releasing said gas includes:

opening said outlet isolation valve;

measuring the pressure of said gas at said point located downstream of said outlet control valve and upstream of said fixed orifice to determine an instantaneous flow rate of said outlet control valve in order to control the conductivity of said outlet control valve;

adjusting the conductivity of said outlet control valve such that said specific mass of gas is released within a predetermined amount of time based upon said instantaneous flow rate; and

shutting said outlet isolation valve after said specific mass of gas is released into said process chamber.

58. The method as cited in claim 57 further comprising the step of:

measuring the temperature and pressure of said gas in order to correct for processing steps, wherein said step of measuring the temperature and pressure of said gas is performed after said step of shutting said outlet isolation valve after said specific mass of gas is released into said process chamber.

59. The method as recited in claim 57 wherein a control system is used to determine the initial conductivity of said outlet control valve which is based upon the pressure and the temperature of said gas in accordance with the following function:

$$pV=nR_uT.$$

60. The method as recited in claim 57 wherein a control system is used to adjust the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

61. The method as recited in claim 57 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

62. The method as recited in claim 57 wherein the pressure of said gas is measured using a capacitance manometer.

63. The method as recited in claims 61 or 62 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system determining the initial conductivity of said outlet control valve which is based upon the pressure and the temperature of said gas in accordance with the following function:

$$pV=nR_uT.$$

64. The method as recited in claims 61 or 62 wherein a computer system having a timer is coupled to said capacitance manometer, said computer system controlling the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

65. The method as recited in claim 57 wherein said gas is a gas mixture.

66. The method as recited in claim 65 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

67. A method for injecting a specific mass of gas into a process chamber at a stable flow rate, said method comprising the steps of:

filling a cavity with a gas, wherein said cavity has a known volume, an inlet isolation valve, an outlet control valve, and an outlet isolation valve and wherein said step of filling said cavity is performed while said inlet isolation valve is open and said outlet isolation valve is closed;

closing said inlet isolation valve of said cavity after said filling step;

measuring the temperature of said gas in said cavity and measuring the pressure of said gas at a point downstream of said outlet control valve and upstream of a fixed orifice to determine the mass of said gas and to set the initial conductivity of said outlet control valve required to release said specific mass of gas into said process chamber;

setting the initial conductivity of said outlet control valve;

releasing said gas into said process chamber, wherein said step of releasing said gas includes:

opening said outlet isolation valve; and

opening said inlet isolation valve;

adjusting the conductivity of said outlet control valve based upon an instantaneous flow rate such that said specific mass of gas is released within a predetermined amount of time, wherein said step of adjusting the conductivity of said outlet control valve includes:

temporarily shutting said inlet isolation valve;

measuring the pressure of said gas at said point located downstream of said outlet control valve and upstream of said fixed orifice to determine said instantaneous flow rate of said outlet control valve in order to control the conductivity of said outlet control valve;

resetting the conductivity of said outlet control valve based upon said instantaneous flow rate;

reopening said inlet isolation valve; and

shutting said outlet isolation valve after said specific mass of gas is released into said process chamber.

68. The method as cited in claim 67 further comprising the step of:

measuring the temperature and pressure of said gas in order to correct for future processing steps, wherein said step of measuring the temperature and pressure of said gas is performed after said step of shutting said outlet isolation valve and after said specific mass of gas is released into said process chamber.

69. The method as recited in claim 67 further comprising the steps of:

determining if said cavity contains enough of said gas to complete the delivery of said specific mass of said gas; and

shutting said inlet isolation valve after it has been determined that said cavity contains enough of said gas to complete the delivery of said specific mass of said gas.

70. The method as recited in claim 67 wherein a control system is used to determine the initial conductivity of said outlet control valve which is based upon the pressure and the temperature of said gas in accordance with the following function:

$$pV=nR_uT.$$

71. The method as recited in claim 67 wherein a control system is used to adjust the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

72. The method as recited in claim 67 wherein the temperature of said gas is measured using a temperature measurement device selected from the group consisting of: a thermocouple and a thermister.

73. The method as recited in claim 67 wherein the pressure of said gas is measured using a capacitance manometer.

74. The method as recited in claims 72 or 73 wherein a computer system having a timer is coupled to said temperature measurement device and said capacitance manometer, said computer system determining the initial conductivity of said outlet control valve based upon the pressure and temperature of said gas in accordance with the following function:

$$pV = nR_uT.$$

75. The method as recited in claims 72 or 73 wherein a computer system having a timer is coupled to said capacitance manometer, said computer system controlling the conductivity of said outlet control valve based upon said instantaneous flow rate in accordance with the following function:

$$\Delta n = \frac{V}{RT}(p_1 - p_2).$$

76. The method as recited in claim 67 wherein said gas is a gas mixture.

77. The method as recited in claim 76 wherein said step of filling said cavity with said gas mixture comprises:

a) turning on an inlet isolation valve for a single gas of a plurality of gases;

b) measuring the pressure and temperature of said gas within said cavity to determine the mass of said single gas within said cavity;

c) shutting off said inlet isolation valve for said single gas when a desired amount of said single gas is determined to be in said cavity based upon said pressure and temperature measurements;

d) repeating steps a) - c) for as many single gases of said plurality of gases as necessary until the desired gas mixture is created within said cavity.

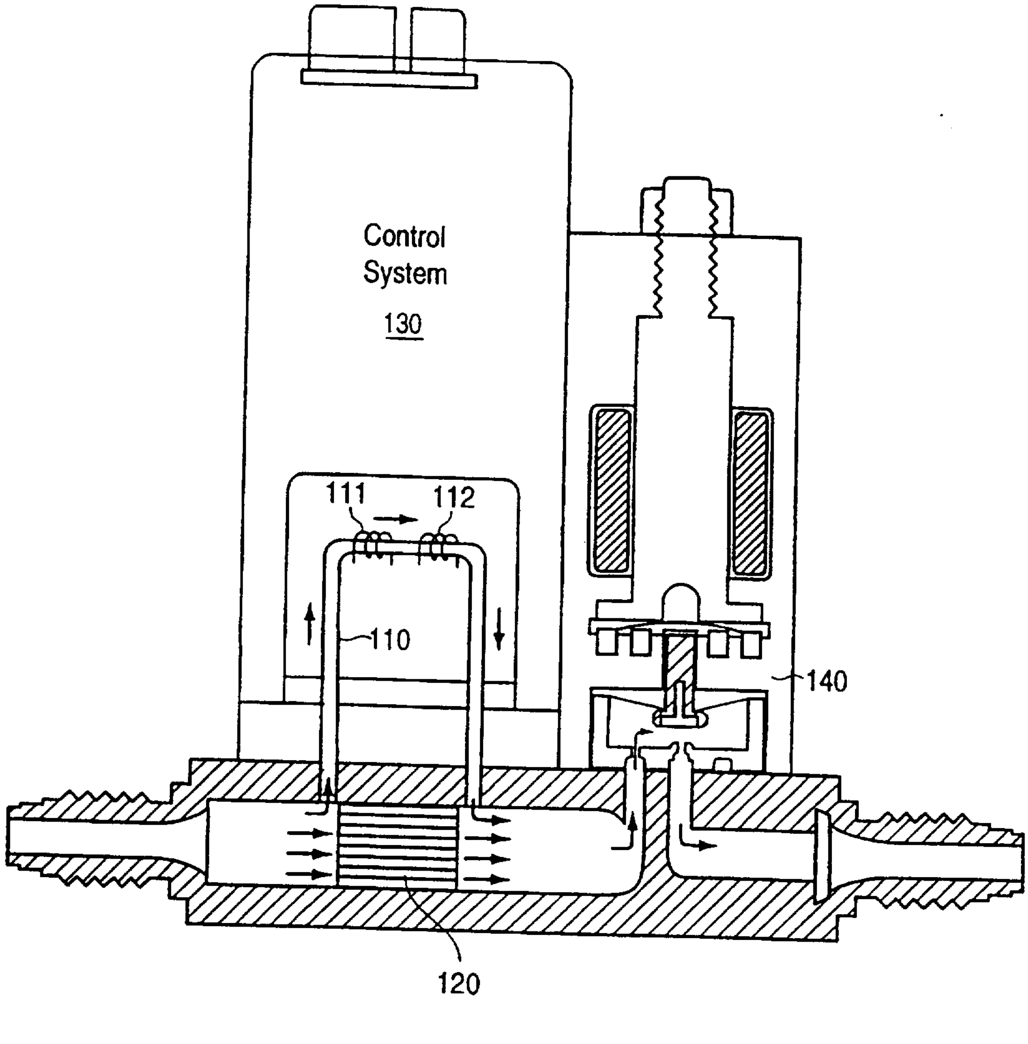


FIG. 1

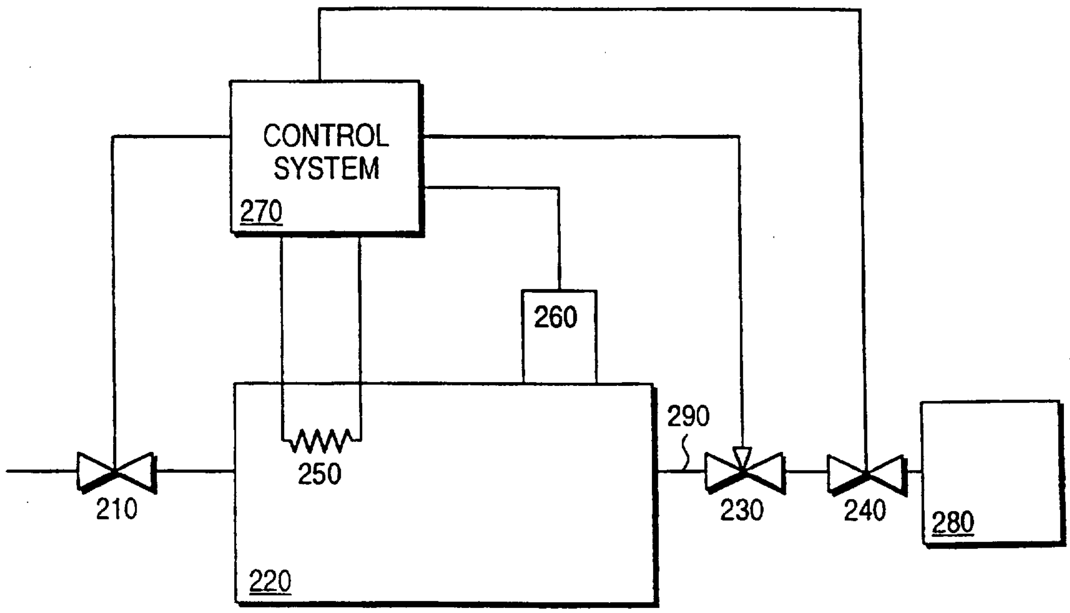


FIG. 2A

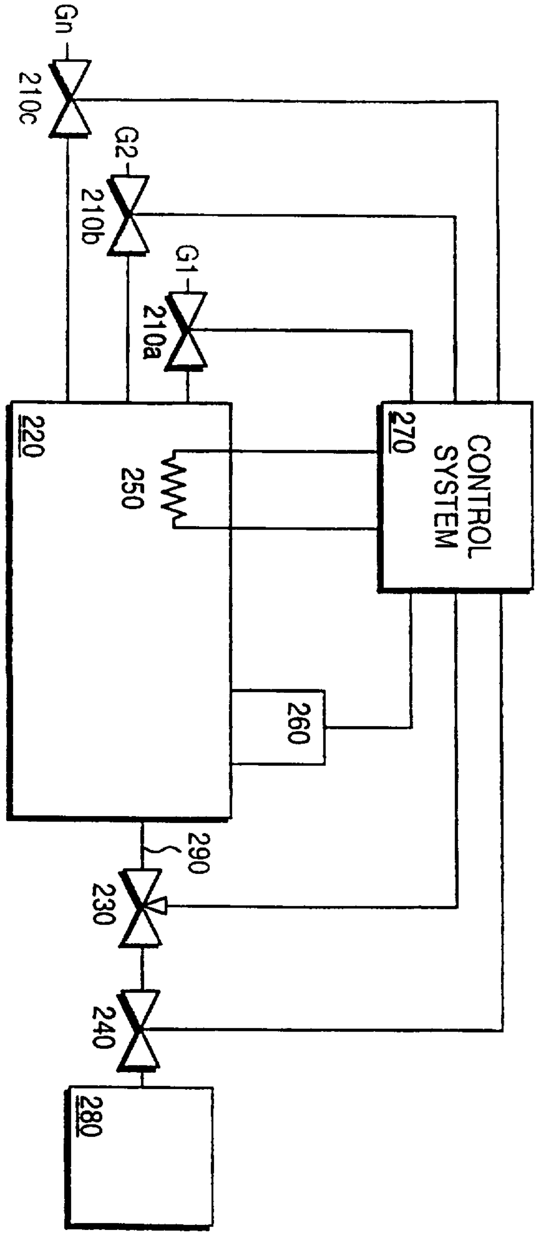

Gn
210c
G2
210b
G1
210a
220
250
270
CONTROL SYSTEM
260
290
230
240
280

FIG. 2B

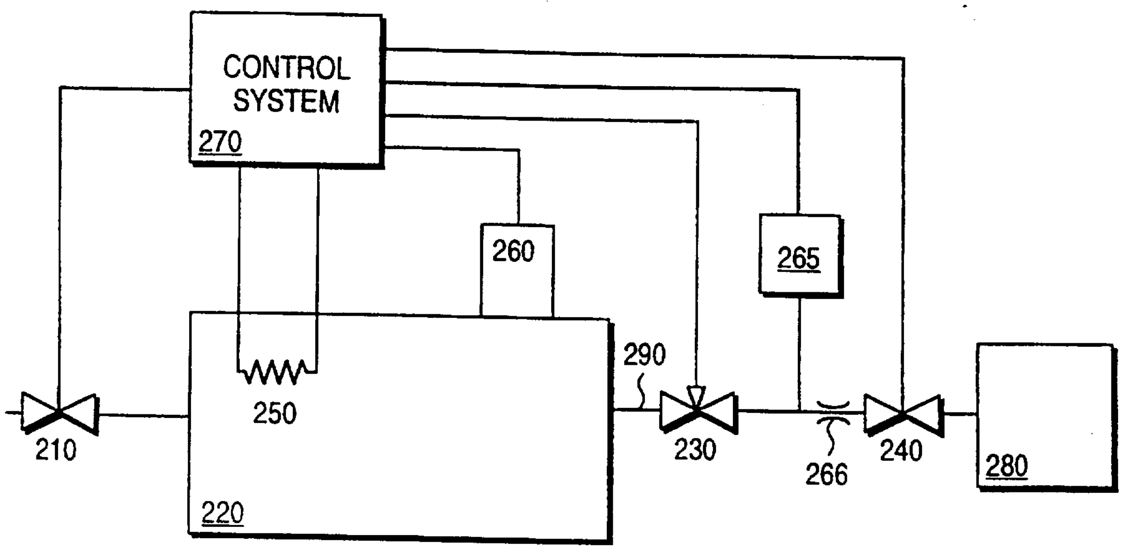


FIG. 2C

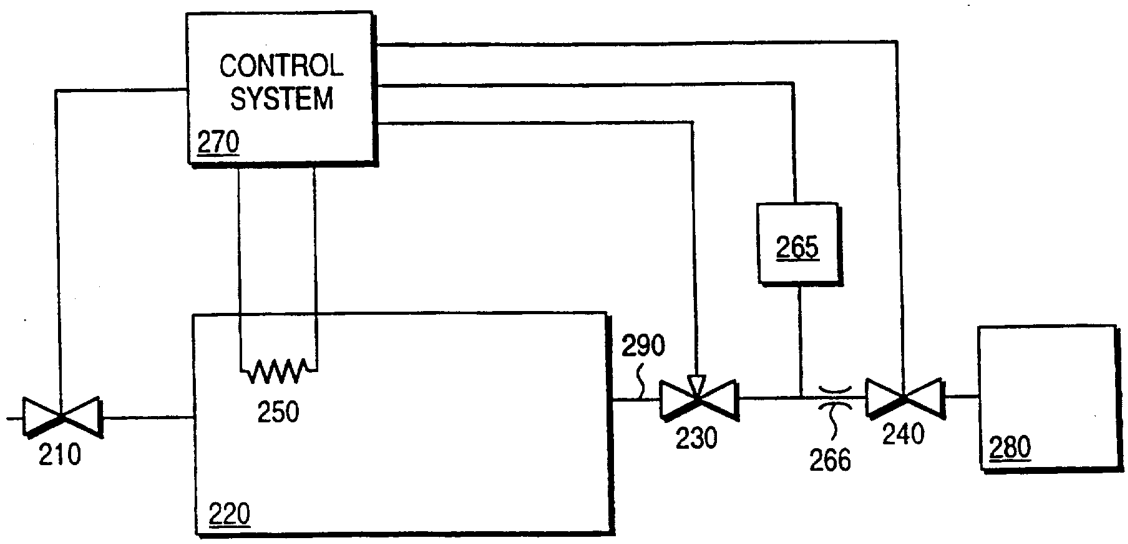


FIG. 2D

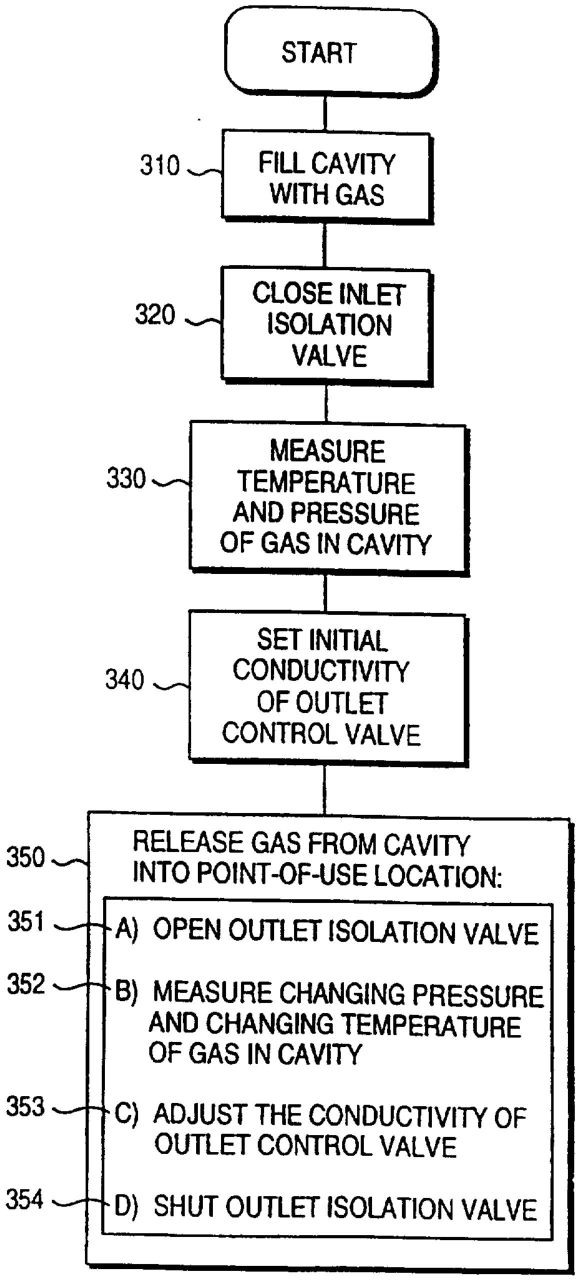

START
310
FILL CAVITY WITH GAS
320
CLOSE INLET ISOLATION VALVE
330
MEASURE TEMPERATURE AND PRESSURE OF GAS IN CAVITY
340
SET INITIAL CONDUCTIVITY OF OUTLET CONTROL VALVE
350
RELEASE GAS FROM CAVITY INTO POINT-OF-USE LOCATION:
351
A) OPEN OUTLET ISOLATION VALVE
352
B) MEASURE CHANGING PRESSURE AND CHANGING TEMPERATURE OF GAS IN CAVITY
353
C) ADJUST THE CONDUCTIVITY OF OUTLET CONTROL VALVE
354
D) SHUT OUTLET ISOLATION VALVE

FIG. 3

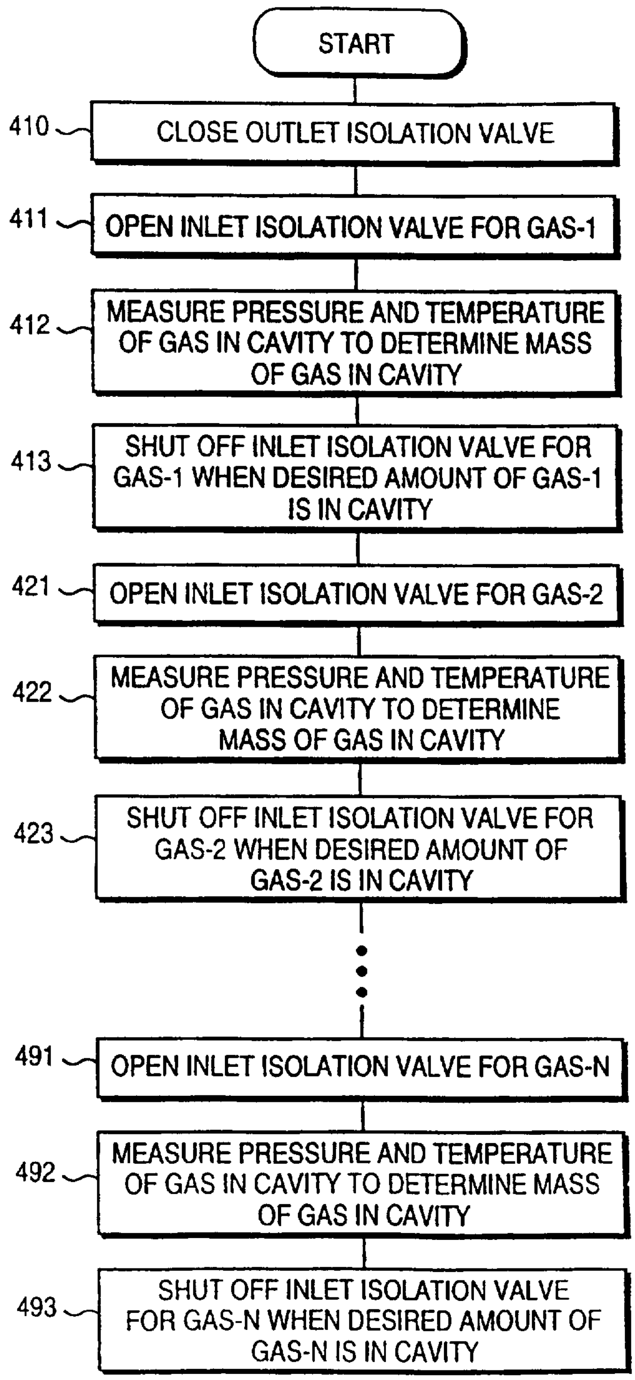

START
410 CLOSE OUTLET ISOLATION VALVE
411 OPEN INLET ISOLATION VALVE FOR GAS-1
412 MEASURE PRESSURE AND TEMPERATURE OF GAS IN CAVITY TO DETERMINE MASS OF GAS IN CAVITY
413 SHUT OFF INLET ISOLATION VALVE FOR GAS-1 WHEN DESIRED AMOUNT OF GAS-1 IS IN CAVITY
421 OPEN INLET ISOLATION VALVE FOR GAS-2
422 MEASURE PRESSURE AND TEMPERATURE OF GAS IN CAVITY TO DETERMINE MASS OF GAS IN CAVITY
423 SHUT OFF INLET ISOLATION VALVE FOR GAS-2 WHEN DESIRED AMOUNT OF GAS-2 IS IN CAVITY
491 OPEN INLET ISOLATION VALVE FOR GAS-N
492 MEASURE PRESSURE AND TEMPERATURE OF GAS IN CAVITY TO DETERMINE MASS OF GAS IN CAVITY
493 SHUT OFF INLET ISOLATION VALVE FOR GAS-N WHEN DESIRED AMOUNT OF GAS-N IS IN CAVITY

FIG. 4

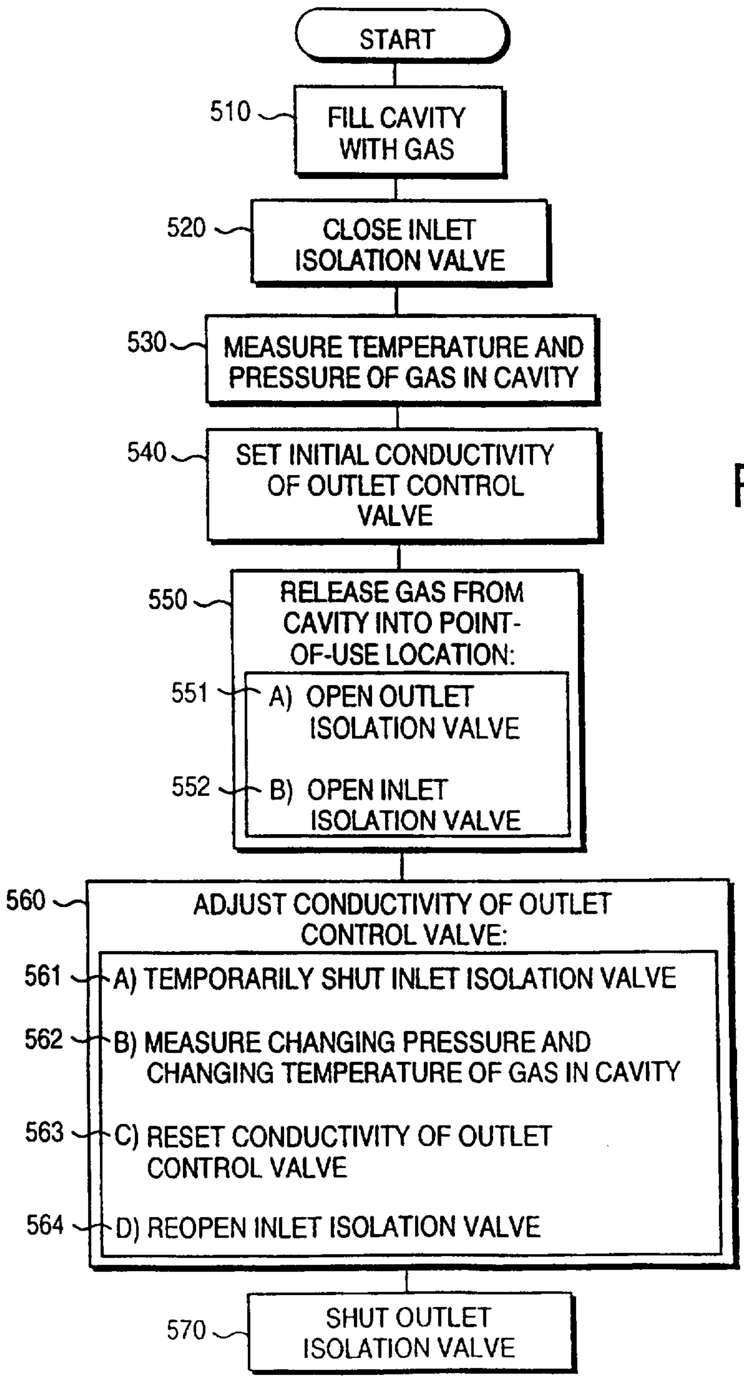
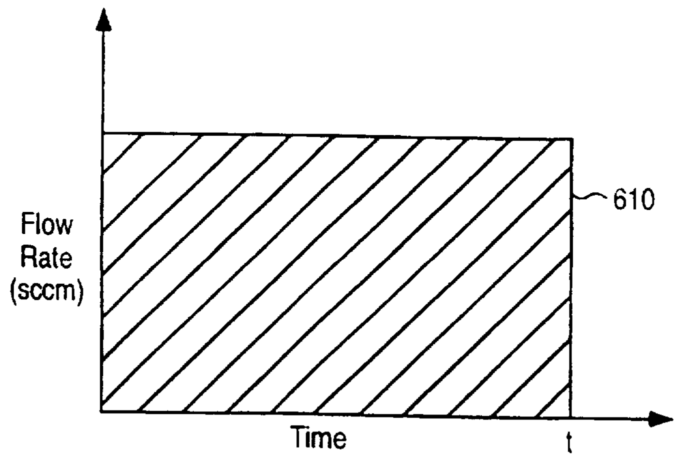

START
510 FILL CAVITY WITH GAS
520 CLOSE INLET ISOLATION VALVE
530 MEASURE TEMPERATURE AND PRESSURE OF GAS IN CAVITY
540 SET INITIAL CONDUCTIVITY OF OUTLET CONTROL VALVE
550 RELEASE GAS FROM CAVITY INTO POINT-OF-USE LOCATION:
551 A) OPEN OUTLET ISOLATION VALVE
552 B) OPEN INLET ISOLATION VALVE
560 ADJUST CONDUCTIVITY OF OUTLET CONTROL VALVE:
561 A) TEMPORARILY SHUT INLET ISOLATION VALVE
562 B) MEASURE CHANGING PRESSURE AND CHANGING TEMPERATURE OF GAS IN CAVITY
563 C) RESET CONDUCTIVITY OF OUTLET CONTROL VALVE
564 D) REOPEN INLET ISOLATION VALVE
570 SHUT OUTLET ISOLATION VALVE

FIG. 5

FIG. 6



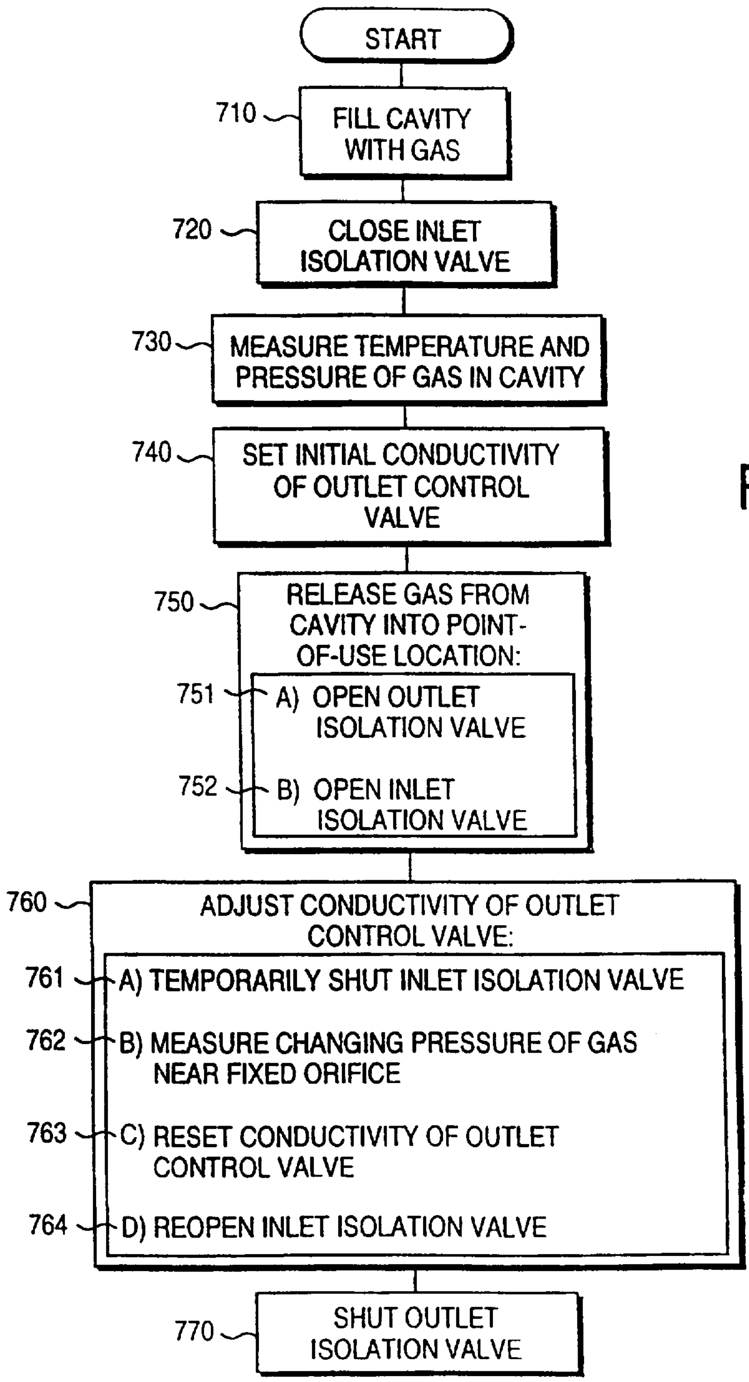

START
710
FILL CAVITY WITH GAS
720
CLOSE INLET ISOLATION VALVE
730
MEASURE TEMPERATURE AND PRESSURE OF GAS IN CAVITY
740
SET INITIAL CONDUCTIVITY OF OUTLET CONTROL VALVE
750
RELEASE GAS FROM CAVITY INTO POINT-OF-USE LOCATION:
751
A) OPEN OUTLET ISOLATION VALVE
752
B) OPEN INLET ISOLATION VALVE
760
ADJUST CONDUCTIVITY OF OUTLET CONTROL VALVE:
761
A) TEMPORARILY SHUT INLET ISOLATION VALVE
762
B) MEASURE CHANGING PRESSURE OF GAS NEAR FIXED ORIFICE
763
C) RESET CONDUCTIVITY OF OUTLET CONTROL VALVE
764
D) REOPEN INLET ISOLATION VALVE
770
SHUT OUTLET ISOLATION VALVE

FIG. 7

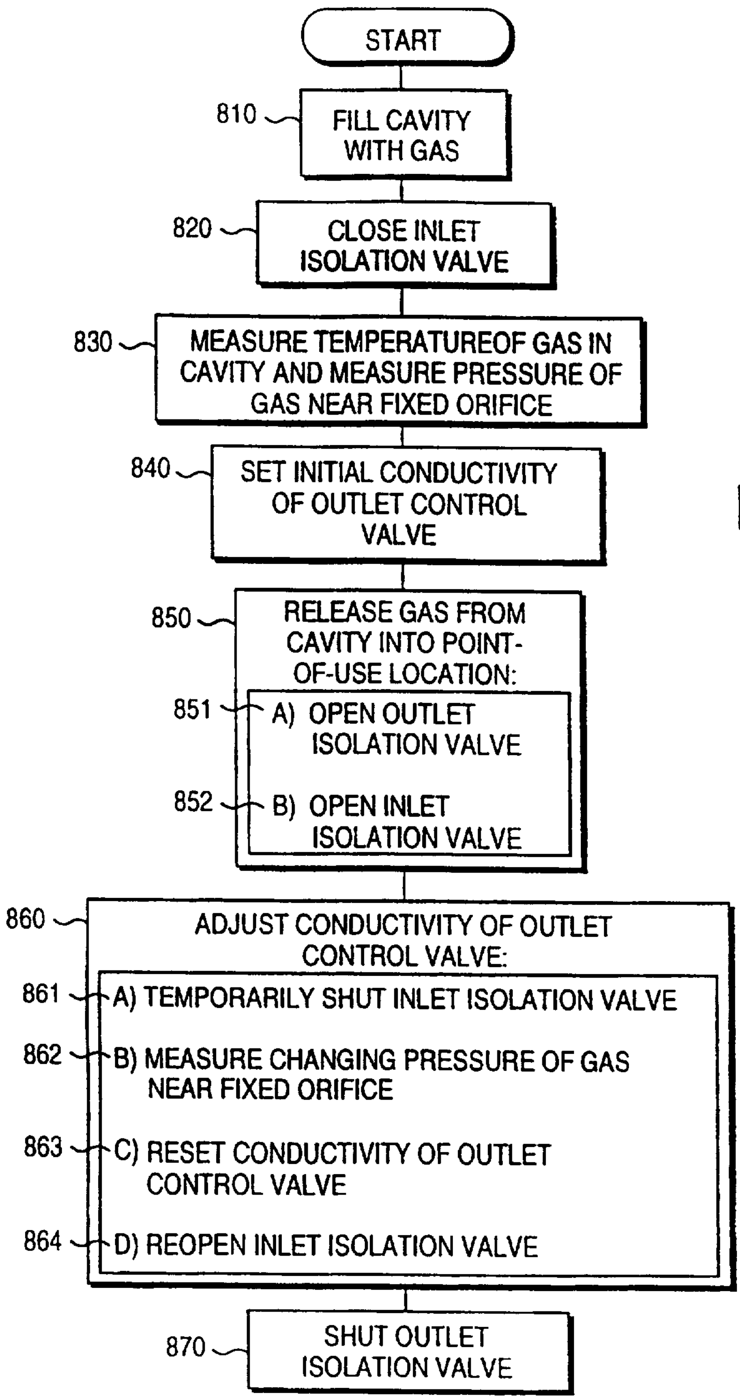

START
810 FILL CAVITY WITH GAS
820 CLOSE INLET ISOLATION VALVE
830 MEASURE TEMPERATUREOF GAS IN CAVITY AND MEASURE PRESSURE OF GAS NEAR FIXED ORIFICE
840 SET INITIAL CONDUCTIVITY OF OUTLET CONTROL VALVE
850 RELEASE GAS FROM CAVITY INTO POINT-OF-USE LOCATION:
851 A) OPEN OUTLET ISOLATION VALVE
852 B) OPEN INLET ISOLATION VALVE
860 ADJUST CONDUCTIVITY OF OUTLET CONTROL VALVE:
861 A) TEMPORARILY SHUT INLET ISOLATION VALVE
862 B) MEASURE CHANGING PRESSURE OF GAS NEAR FIXED ORIFICE
863 C) RESET CONDUCTIVITY OF OUTLET CONTROL VALVE
864 D) REOPEN INLET ISOLATION VALVE
870 SHUT OUTLET ISOLATION VALVE

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/03893

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G05D 7/06
US CL :137/2, 3, 487.5, 606; 73/223, 861.02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 137/2, 3, 8, 487.5, 606; 73/223, 708, 861.02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,394,871 A (CZAJKA et al.) 26 July 1983, see entire document.	1-77
A	US 5,152,309 A (TWERDOCHLIB et al.) 06 October 1992, see entire document.	1-77
A	US 5,146,941 A (STATLER) 15 September 1992, see entire document.	1-77

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 JUNE 1997	24 JUL 1997
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer J. Hurley for STEPHEN M. HEPPERLE
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