CLAIMS

What is claimed is:

1. A pulse gas delivery system comprising:

a chamber having a volume;

a pressure sensor configured to detect pressure of gas within the chamber;

a temperature sensor configured to detect a temperature indicative of temperature of the gas within the chamber;

an upstream valve configured to control flow of a gas into the chamber;

a downstream adjustable control valve, the openness of which can be controlled, configured to control flow rate of the gas out of the chamber; and

a controller configured to control the upstream valve and the downstream control valve to charge the chamber to an initial pressure and to thereafter control measured flow rate through the downstream control valve during a gas pulse of the gas flowing out of the chamber to control delivered dose and period of the gas pulse, measured flow rate being calculated from a rate of pressure decay calculation based on the detected pressure and temperature~~.~~, and

wherein the controller is further configured to control the downstream control valve to regulate the measured flow rate of the gas out of the chamber calculated from the rate of pressure decay calculation during the gas pulse to a targeted flow rate set point.

2. The pulse gas delivery system of claim 1, wherein the controller is configured to control opening of the downstream control valve in a feedback loop to regulate the flow rate out of the system during the pulse based on pressure and temperature detected during the pulse.

~~3. The pulse gas delivery system of claim 1, wherein the controller is further configured to calculate flow rate of the gas out of the chamber and to control the downstream control valve to regulate the flow rate of the gas out of the chamber based on the calculated flow rate and a targeted flow set point.~~

3~~4~~. The ~~pressure based~~ pulse gas delivery system of claim ~~3~~1, wherein the controller is configured to calculate the flow rate Q based on the following function:

$$Q = -\frac{V \times T_{stp}}{P_{stp}} \frac{d\left(\frac{P}{T}\right)}{dt}$$

where V represents the volume of the chamber, T_{stp} represents standard temperature, P_{stp} represents standard pressure, P represents the pressure of the gas within the chamber, and T represents the temperature of the gas within the chamber.

45. The pulse gas delivery system of claim 31, wherein the controller is further configured to calculate a dose of the gas delivered out of the chamber and to control the downstream control valve to deliver a prescribed dose of gas during a prescribed period of the gas pulse.

56. The pulse gas delivery system of claim 45, wherein the controller is configured to calculate the dose of the gas delivered out of the chamber based on volume of the chamber, the initial pressure of the gas within the chamber as detected by the pressure sensor when the pulse is started, the pressure of the gas within the chamber as detected by the pressure sensor during the pulse, and the temperature of the gas as detected by the temperature sensor during the pulse.

67. The pulse gas delivery system of claim 56, wherein the controller is configured to calculate the dose $\Delta n(t)$ of the gas delivered out of the chamber at a time t during the pulse according to the following function:

$$\Delta n(t) = V \times (P_{t0} - P_t)/(\mathrm{R} \times T_t),$$

where V represents the volume of the chamber, P_{t0} represents the pressure of the gas within the chamber when the pulse is started, P_t represents the pressure of the gas within the chamber at the time t during the pulse, and T_t represents the temperature of the gas at the time t during the pulse.

78. The pulse gas delivery system of claim 1, wherein the controller is further configured to calculate a dose of the gas delivered out of the chamber and to control the downstream control valve to deliver a prescribed dose of gas during a prescribed period of the gas pulse.

89. The pulse gas delivery system of claim 78, wherein the controller is configured to calculate the dose of the gas delivered out of the chamber based on the volume of the

chamber, the initial pressure of the gas within the chamber as detected by the pressure sensor when the pulse is started, the pressure of the gas within the chamber as detected by the pressure sensor during the pulse, and the temperature of the gas as detected by the temperature sensor during the pulse.

9~~10~~. The pulse gas delivery system of claim 8~~9~~, wherein the controller is configured to calculate the dose $\Delta n(t)$ of the gas delivered out of the chamber at a time t during the pulse according to the following function:

$$\Delta n(t) = V \times (P_{t0} - P_t)/(R \times T_t),$$

where V represents the volume of the chamber, P_{t0} represents the pressure of the gas within the chamber when the pulse is started, P_t represents the pressure of the gas within the chamber at the time t during the pulse, and T_t represents the temperature of the gas at the time t during the pulse.

10~~11~~. The pulse gas delivery system of claim 1, wherein the controller is configured to adjust the flow rate during the pulse to achieve a prescribed pulse shape.

11~~12~~. The pulse gas delivery system of claim 1, wherein the controller is configured to adjust the downstream control valve to achieve a ~~substantially~~ constant flow rate during the pulse.

12~~13~~. A method of pulse gas delivery comprising:

(i) opening an upstream valve while closing a downstream adjustable control valve to charge a chamber with a gas to an initial pressure;

(ii) closing the upstream valve when the initial pressure is reached;

(iii) once the initial pressure is reached and after the upstream valve is closed, opening the downstream adjustable control valve to start a pulse of the gas flowing out of the chamber;

(iv) measuring flow rate from a rate of pressure decay calculation during the pulse of the gas based on pressure and temperature of the gas in the chamber; and

(v) controlling openness of the downstream adjustable control valve during the pulse of the gas flowing out of the chamber to regulate the measured flow rate from the rate of pressure decay calculation to a targeted flow rate set point during the pulse of the gas and to deliver a prescribed dose over a prescribed period of the pulse.

13~~14~~. The method of pulse gas delivery as claimed in claim 12~~13~~, further comprising detecting, during the pulse, pressure and temperature of the gas within the chamber and controlling the downstream control valve based on the detected pressure and temperature.

14~~15~~. The method of pulse gas delivery as claimed in claim 12~~13~~, further comprising controlling the downstream control valve to be closed when the prescribed dose of gas is reached.

15~~16~~. The method of pulse gas delivery as claimed in claim 12~~13~~, further comprising controlling the downstream control valve to be closed when a desired pulse on time is reached.

16~~17~~. The method of pulse gas delivery as claimed in claim 12~~13~~, further comprising repeating (i) to (iv) under control of a dedicated controller for a number of pulses.

~~18. The method of pulse gas delivery as claimed in claim 13 further comprising measuring flow rate of gas out of the chamber and controlling, during the pulse, the downstream control valve to adjust the measured flow rate to a targeted flow set point.~~

17~~19~~. The method of pulse gas delivery as claimed in claim 12~~13~~ further comprising, during the pulse, computing a dose of gas delivered out of the chamber and controlling the downstream control valve to deliver a prescribed dose of gas during a prescribed pulse time.

18~~20~~. The method of pulse gas delivery as claimed in claim 12~~13~~ further comprising adjusting flow rate during the pulse to achieve a prescribed pulse shape.

19~~21~~. The method of pulse gas delivery as claimed in claim 12~~13~~ further comprising adjusting the downstream control valve during the pulse to achieve a ~~substantially~~ constant flow rate during the pulse.

20~~22~~. A method of delivering a pulse of ~~fluid~~gas, the method comprising:

~~controlling flow of fluid into a chamber with an inlet valve;~~

opening an upstream valve while closing a downstream adjustable control valve to charge a chamber with a gas to an initial pressure;

closing the upstream valve when the initial pressure is reached;

once the initial pressure is reached and after the upstream valve is closed, opening the downstream adjustable control valve to start a pulse of the gas flowing out of the chamber;

detecting a pressure of the gas within the chamber with a pressure sensor;

detecting a temperature indicative of temperature of the gas within the chamber with a temperature sensor; and

regulating measured flow rate of the gas during the pulse of the gas flowing out of the chamber to a targeted flow rate set point by controlling ~~flow of fluid through a~~ the downstream adjustable control valve during the pulse of ~~fluid~~the gas, the measured flow rate being calculated from a rate of pressure decay calculation based on the detected pressure and temperature.

21~~23~~. The method of claim 20~~22~~, wherein controlling the flow rate of ~~fluid~~the gas through the downstream control valve is based on feedback from the pressure and the temperature detected during the pulse.

~~24. The method of claim 22, further comprising:~~

~~calculating flow rate of the gas out of the chamber and controlling the downstream control valve to regulate the flow rate of the gas out of the chamber based on the calculated flow rate and a targeted flow set point.~~

22~~25~~. The method of claim 20~~4~~, further comprising:

calculating the flow rate Q based on the following function:

$$Q = -\frac{V \times T_{stp}}{P_{stp}} \frac{d\left(\frac{P}{T}\right)}{dt},$$

where V represents volume of the chamber, T_{stp} represents standard temperature, P_{stp} represents standard pressure, P represents the pressure of the gas within the chamber, and T represents the temperature of the gas within the chamber.

23~~26~~. The method of claim 20~~22~~, further comprising:

calculating a dose of the gas delivered out of the chamber and controlling the downstream control valve to deliver a prescribed dose of gas during a prescribed period of the gas pulse.

24~~27~~. The method of claim 20~~22~~, further comprising:

calculating the dose of the gas delivered out of the chamber based on volume of the chamber, initial pressure of the gas within the chamber as detected by the pressure sensor when the pulse is started, the pressure of the gas within the chamber as detected by the pressure sensor during the pulse, and the temperature of the gas as detected by the temperature sensor during the pulse.

25~~28~~. The method of claim 24~~27~~, further comprising:

calculating the dose $\Delta n(t)$ of the gas delivered out of the chamber at a time t during the pulse according to the following function:

$$\Delta n(t) = V \times (P_{t0} - P_t)/(\mathrm{R} \times T_t),$$

where V represents the volume of the chamber, P_{t0} represents the pressure of the gas within the chamber when the pulse is started, P_t represents the pressure of the gas within the chamber at the time t during the pulse, and T_t represents the temperature of the gas at the time t during the pulse.

26~~29~~. The method of claim 20~~22~~, further comprising:

adjusting flow rate during the pulse to achieve a prescribed pulse shape.

27~~30~~. The method of claim 20~~22~~, further comprising:

adjusting the downstream control valve to achieve a ~~substantially~~ constant flow rate during the pulse.