CLAIMS

What is claimed is:

1. A pulse gas control system, the system comprising:

a gas concentration measurement system configured to measure a concentration of a process gas in a gas mixture; and

a pulse gas delivery system configured to sense flow of the gas mixture and control flow of the gas mixture and to receive the concentration of the process gas in the gas mixture, measured by the gas concentration measurement system, and to control an amount of gas mixture delivered in a pulse of gas flow based on the received concentration of the process gas to control a mole amount of the process gas delivered to a process chamber in each pulse;

the pulse gas delivery system including a sensor to sense the flow of the gas mixture and a control valve to regulate flow of the gas mixture to a flow setpoint during a pulse duration period;

the pulse gas delivery system configured to adjust the flow setpoint, during the pulse duration period, based on a changed measured concentration during the pulse duration period; and

the pulse gas delivery system configured to maintain a constant pulse duration while adjusting the flow setpoint over time during the pulse duration period until the pulse duration period is complete;

wherein the pulse gas delivery system is configured to maintain the constant pulse duration until a total process gas mole delivery per pulse setpoint is reached, the adjusting the flow setpoint comprising adjusting the flow setpoint over time during the pulse duration period based on the remaining time within the pulse and the remaining mole amount of process gas to be delivered within the pulse out of the total process gas mole delivery per pulse setpoint.

2. The system of Claim 1, wherein the pulse gas delivery system is configured to set an initial target flow setpoint of the gas mixture in inverse proportion to the received concentration of the process gas.

3. The system of Claim 2, wherein the pulse gas delivery system is configured to set the initial target flow setpoint in proportion to a process gas mole delivery per pulse setpoint divided by a product of a pulse duration period multiplied by the received concentration of the process gas.

4. The system of Claim 1, wherein the pulse gas delivery system is configured to adjust the flow setpoint based on a relationship:

$$Q_{sp}(t) = \frac{k \cdot M_{sp} - \int_{t_0}^{t} Q_m(t) C(t) dt}{(\Delta t - (t - t_0)) \cdot C(t)}$$

where $Q_{sp}(t)$ is the flow setpoint, k is a mole to flow unit conversion constant, M_{sp} is a process gas mole delivery per pulse setpoint, $Q_m(t)$ is a measured flow rate of the pulse gas delivery system, C(t) is the received process gas concentration, Δt is the pulse duration period, t is a current time, and t_0 is an initial time of the pulse duration period.

5. The system of Claim 1, wherein the gas concentration measurement system comprises an optical gas sensor, a surface acoustic wave device, an ultrasound sensor, a mass spectrometer or a thermal conductive detector.

6. The system of Claim 1, wherein the gas concentration measurement system is arranged in series between a source of the gas mixture and the pulse gas delivery system, to receive the gas mixture from a source and to provide the gas mixture to the pulse gas delivery system.

7. The system of Claim 1, wherein the gas concentration measurement system is arranged to receive a sample of the gas mixture from a sample line that samples a gas flow of the gas mixture from a source to the pulse gas delivery system.

8. The system of Claim 1, wherein the process chamber to which the pulse gas delivery system is configured to deliver the process gas is one of: an Atomic Layer Deposition (ALD) process, an Atomic Layer Etch (ALE) process, a Through Silicon Via (TSV) process, a pulsed deep reactive ion etch (DRIE) process, a plasma enhanced chemical vapor deposition (CVD) process and a plasma enhanced etching process.

9. The system of Claim 1, wherein the pulse gas delivery system is configured to receive the concentration of the process gas in the gas mixture at an update rate that is at least ten times a pulse frequency that corresponds to a pulse duration period of the pulse gas delivery system.

10. The system of Claim 1, comprising a heater configured to maintain at least part of the flow of the gas mixture comprising the process gas at an elevated temperature.

11. The system of Claim 10, wherein the pulse gas delivery system is configured to control the heater to maintain a substantially constant elevated temperature of the process gas along at least part of the flow of the gas mixture between a source and the process chamber.

12. A method of controlling a pulse gas delivery system, the method comprising:

measuring a concentration of a process gas in a gas mixture;

with the pulse gas delivery system, receiving the concentration of the process gas in the gas mixture;

controlling an amount of gas mixture delivered in a pulse of gas flow by the pulse gas delivery system based on the received concentration of the process gas to control a mole amount of the process gas delivered to a process chamber in each pulse;

wherein the pulse gas delivery system includes a sensor to sense flow of the gas mixture and a control valve to regulate flow of the gas mixture to a flow setpoint during a pulse duration period;

the method comprising adjusting the flow setpoint, during the pulse duration period, based on a changed measured concentration during the pulse duration period;

maintaining a constant pulse duration while adjusting the flow setpoint over time during the pulse duration period until the pulse duration period is complete; and

maintaining the constant pulse duration a total process gas mole delivery per pulse setpoint is reached, the adjusting the flow setpoint comprising adjusting the flow setpoint over time during the pulse duration period based on the remaining time

within the pulse and the remaining mole amount of process gas to be delivered within the pulse out of the total process gas mole delivery per pulse setpoint.

13. The method of Claim 12, comprising setting an initial target flow setpoint of the gas mixture in inverse proportion to the received concentration of the process gas.

14. The method of Claim 13, comprising setting the initial target flow setpoint in proportion to a process gas mole delivery per pulse setpoint divided by a product of a pulse duration period multiplied by the received concentration of the process gas.

15. The method of Claim 12, comprising adjusting the flow setpoint based on a relationship:

$$Q_{sp}(t) = \frac{k \cdot M_{sp} - \int_{t_0}^{t} Q_m(t) C(t) dt}{(\Delta t - (t - t_0)) \cdot C(t)}$$

where $Q_{sp}(t)$ is the flow setpoint, k is a mole to flow unit conversion constant, M_{sp} is a process gas mole delivery per pulse setpoint, $Q_m(t)$ is a measured flow rate of the pulse gas delivery system, C(t) is the received process gas concentration, Δt is the pulse duration period, t is a current time, and t_0 is an initial time of the pulse duration period.

16. The method of Claim 12, comprising measuring the concentration of the process gas in the gas mixture using an optical gas sensor, a surface acoustic wave device, an ultrasound sensor, a mass spectrometer or a thermal conductive detector.

17. The method of Claim 12, comprising using the pulse gas delivery system to deliver the process gas to one of: an Atomic Layer Deposition (ALD) process, an Atomic Layer Etch (ALE) process, a Through Silicon Via (TSV) process, a pulsed deep reactive ion etch (DRIE) process, a plasma enhanced chemical vapor deposition (CVD) process and a plasma enhanced etching process.

18. The method of Claim 12, comprising receiving the concentration of the process gas in the gas mixture at an update rate that is at least ten times a pulse frequency that corresponds to a pulse duration period of the pulse gas delivery system.

19. The method of Claim 12, comprising using a heater to maintain at least part of the flow of the gas mixture comprising the process gas at an elevated temperature.

20. The method of Claim 19, comprising controlling the heater to maintain a substantially constant elevated temperature of the process gas along at least part of the flow of the gas mixture between a source and the process chamber.