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.

2. The pulse gas control system of Claim 1, wherein the pulse gas delivery system is configured to adjust a flow setpoint of the gas mixture during the pulse.

3. The pulse gas control system of Claim 2, wherein the pulse gas delivery system is configured to adjust the flow setpoint of the gas mixture based on the received concentration of the process gas.

4. The system of Claim 3, wherein the pulse gas delivery system sets an initial target flow setpoint of the gas mixture in inverse proportion to the received concentration of the process gas.

5. The system of Claim 4, wherein the pulse gas delivery system sets 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.

6. The system of Claim 2, wherein the pulse gas delivery system adjusts the flow setpoint, during a pulse duration period, based on a changed measurement of the process gas concentration during the pulse duration period.

7. The system of Claim 6, wherein the pulse gas delivery system adjusts 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.

8. The system of Claim 6, wherein the pulse gas delivery system adjusts the flow setpoint over time during the pulse duration period until the pulse duration period is complete.

9. The system of Claim 2, wherein the pulse gas delivery system maintains a constant pulse duration while adjusting the flow setpoint.

10. 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.

11. 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.

12. 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.

13. 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.

14. The system of Claim 1, wherein the pulse gas delivery system is configured to adjust a pulse duration used to deliver the gas mixture to the process chamber.

15. The system of Claim 14, wherein the pulse gas delivery system is configured to adjust the pulse duration by ending the pulse duration when a total mole amount of process gas delivered is greater than or equal to a process gas mole delivery per pulse setpoint.

16. The system of Claim 14, wherein the pulse gas delivery system is configured to adjust a flow setpoint of the gas mixture during the pulse and to adjust the pulse duration.

17. 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.

18. 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.

19. The system of Claim 18, 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.

20. 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; and

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.

21. The method of Claim 20, comprising adjusting a flow setpoint of the gas mixture during the pulse.

22. The method of Claim 21, comprising adjusting the flow setpoint of the gas mixture based on the received concentration of the process gas.

23. The method of Claim 22, comprising setting an initial target flow setpoint of the gas mixture in inverse proportion to the received concentration of the process gas.

24. The method of Claim 23, 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.

25. The method of Claim 21, comprising adjusting the flow setpoint, during a pulse duration period, based on a changed measurement of the process gas concentration during the pulse duration period.

26. The method of Claim 25, 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.

27. The method of Claim 25, comprising adjusting the flow setpoint over time during the pulse duration period until the pulse duration period is complete.

28. The method of Claim 21, comprising maintaining a constant pulse duration while adjusting the flow setpoint.

29. The method of Claim 20, 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.

30. The method of Claim 20, 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.

31. The method of Claim 20, comprising adjusting a pulse duration used to deliver the gas mixture to the process chamber.

32. The method of Claim 31, comprising adjusting the pulse duration by ending the pulse duration when a total mole amount of process gas delivered is greater than or equal to a process gas mole delivery per pulse setpoint.

33. The method of Claim 31, comprising adjusting a flow setpoint of the gas mixture during the pulse and adjusting the pulse duration.

34. The method of Claim 20, 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.

35. The method of Claim 20, comprising using a heater to maintain at least part of the flow of the gas mixture comprising the process gas at an elevated temperature.

36. The method of Claim 35, 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.

37. The system of Claim 1, wherein the pulse gas delivery system includes 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 adjusting the flow setpoint, during the pulse duration period, based on a changed measured concentration during the pulse duration period to control the amount of gas mixture delivered in the pulse of gas flow, based on the measured concentration of the process gas, to control the mole amount of the process gas delivered to the process chamber during the pulse duration period; and

the pulse gas delivery system 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 a total process gas mole delivery per pulse setpoint is reached, the adjusting 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.

38. The method of Claim 20, wherein the measuring the concentration of the process gas in the gas mixture comprises using a gas concentration measurement system;

and 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 to control the amount of gas mixture delivered in the pulse of gas flow by the pulse gas delivery system, based on the measured concentration of the process gas, to control the mole amount of the process gas delivered to the process chamber during the pulse duration period; and

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 a total process gas mole delivery per pulse setpoint is reached, the adjusting 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.