(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 September 2013 (06.09.2013)

(10) International Publication Number
WO 2013/130737 A1

(51) **International Patent Classification**:
H01L 21/205 (2006.01)

(21) **International Application Number**:
PCT/US2013/028214

(22) **International Filing Date**:
28 February 2013 (28.02.2013)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
61/605,231 1 March 2012 (01.03.2012) US
13/779,056 27 February 2013 (27.02.2013) US

(71) **Applicant**: **NOVELLUS SYSTEMS, INC.** [US/US]; 4000 North First Street, San Jose, California 95134 (US).

(72) **Inventor**: **LEESER, Karl**; 6152 SW Bonita Rd. Apt. A201, Lake Oswego, Oregon 97035 (US).

(74) **Agents**: **WIGGINS, Michael D.** et al.; Harness, Dickey & Pierce, P.L.C., P.O. Box 828, Bloomfield Hills, Michigan 48303 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *with amended claims (Art. 19(1))*

(54) **Title**: SEQUENTIAL CASCADING OF REACTION VOLUMES AS A CHEMICAL REUSE STRATEGY

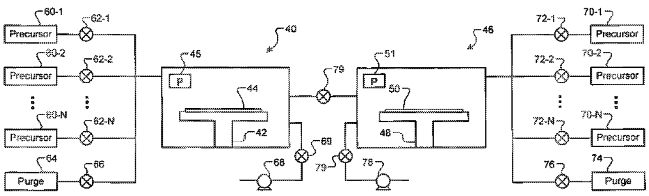


FIG. 3

(57) **Abstract**: A substrate processing system includes one or more processing chambers defining N reaction volumes. N-1 first valves are arranged between the N reaction volumes. A controller communicates with the N-1 first valves and is configured to pressurize a first one of the N reaction volumes with precursor gas to a first target pressure, wait a first predetermined soak period, evacuate a second one of the N reaction volumes to a second target pressure that is lower than the first target pressure, and open one of the N-1 first valves between the first one of the N reaction volumes and a second one of the N reaction volumes.

WO 2013/130737 A1

SEQUENTIAL CASCADING OF REACTION VOLUMES AS A CHEMICAL REUSE STRATEGY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Utility Application No. 13/779,056, filed on February 27, 2013, and the benefit of U.S. Provisional Application No. 61/605,231, filed on March 1, 2012. The entire disclosures of the applications referenced above are incorporated herein by reference.

FIELD

[0002] The present disclosure relates to substrate processing chambers, and more particularly to semiconductor processing chambers.

BACKGROUND

[0003] The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0004] Some vapor-based reaction technologies and their associated applications, such as dielectric constant (k) recovery and atomic layer deposition (ALD), require expensive precursor gas. These processes involve exposing a substrate to the precursor gas at a target pressure, allowing the substrate to soak and then dumping the precursor gas (an expose/soak/dump sequence). To minimize the use of the precursor gas, significant effort has been expended to minimize reaction volumes, which reduces precursor gas consumption per wafer. However, the smaller reaction volumes may cause other undesirable reactor design compromises, which may increase cost on a per-wafer pass basis.

[0005] Referring now to FIG. 1, a first reaction volume 10 is shown. A pedestal 12 is arranged in the first reaction volume 10 and provides support for a substrate 14 such as a semiconductor wafer. Precursor gases 20-1, 20-2, ..., and 20-N (collectively precursor gases 20) are supplied via valves 22-1, 22-2, …, and 22-N (collectively valves 20) to the first reaction volume 10, wherein N is an integer. Purge gas 24 is supplied via a valve 26 to the first reaction volume 10. A pump 30 may be used to selectively draw precursor gas and/or purge gas from the first reaction volume 10.

[0006] Referring now to FIG. 2, a method for operating the first reaction volume 10 is shown. At 31, N=1. At 32, the substrate 14 is arranged in the first reaction volume 10 and is exposed to a first precursor gas at a target pressure. At 34, the substrate 14 is allowed to soak in the precursor gas for a predetermined period. At 36, the precursor gas is purged from the first reaction volume 10 and discarded. At 38, if another precursor gas is to be used, control returns to 32. Optionally the sequence may cycle via 39 and 41. Otherwise the process ends.

SUMMARY

[0007] A substrate processing system includes one or more processing chambers defining N reaction volumes, wherein N is an integer greater than one. N-1 first valves are arranged between the N reaction volumes. A controller is in communication with the N-1 first valves and is configured to pressurize a first one of the N reaction volumes with precursor gas to a first target pressure, wait a first predetermined soak period, evacuate a second one of the N reaction volumes to a second target pressure that is lower than the first target pressure, and open one of the N-1 first valves between the first one of the N reaction volumes and a second one of the N reaction volumes.

[0008] In other features, N pressure sensors measure pressure in the N reaction volumes, respectfully. The controller is configured to communicate with the N pressure sensors. N pumps are in fluid communication with the N reaction volumes via N second valves. The controller is configured to selectively operate the N pumps and the N second valves.

[0009] In other features, the controller is configured to wait until a predetermined pressure relationship exists between the first one of the N

reaction volumes and the second one of the N reaction volumes, and close the one of the N-1 first valves. The predetermined pressure relationship is pressure equilibrium.

[0010] In other features, the controller is configured to introduce an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure after closing the one of the N-1 first valves.

[0011] In other features, the controller is configured to purge residual precursor gas from the first one of the N reaction volumes.

[0012] In other features, the controller is configured to wait a second predetermined soak period and cascade the precursor gas in the second one of the N reaction volumes to an additional one of the N reaction volumes.

[0013] In still other features, N-1 compressors and N-1 second valves are arranged between the N reaction volumes. The controller is further in communication with the N-1 compressors and the N-1 second valves. The controller is configured to, after evacuating the second one of the N reaction volumes to the second target pressure, open one of the N-1 second valves between the first one of the N reaction volumes and the second one of the N reaction volumes, and operate one of the N-1 compressors to drive the precursor gas from the first one of the N reaction volumes to the second one of the N reaction volumes.

[0014] In other features, the controller is configured to close the one of the N-1 first valves and the one of the N-1 second valves. The controller is configured to add an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure. The controller is configured to purge residual precursor from the first one of the N reaction volumes.

[0015] A substrate processing including a processing chamber defining a reaction volume. A first valve is arranged between the reaction volume and a storage volume. A controller is in communication with the first valve and is configured to pressurize the reaction volume with precursor gas to a first target pressure, wait a predetermined soak period, evacuate the storage volume to a pressure that is lower than the first target pressure and open the first valve.

[0016] In other features, the controller communicates with a second valve and a compressor and is configured to operate the first valve, the second valve and the compressor to drive the precursor gas from the reaction volume to the storage volume

[0017] In other features, a pressure sensor measures pressure in the reaction volume. A pump is in fluid communication with the reaction volume via a second valve. The controller communicates with the pressure sensor, the pump and the second valve. The controller is configured to close the first valve and the second valve. The controller is configured to purge residual precursor from the reaction volume. The controller is configured to open the first valve and the second valve between the reaction volume and the storage volume and operate the compressor to drive the precursor gas from the storage volume to the reaction volume.

[0018] In other features, N additional reaction volumes and N additional valves connect the N additional reaction volumes to the compressor. The controller is configured to open one of the first valve or one of the N additional valves, open the second valve, and operate the compressor to pump the precursor gas from the storage volume to one of the reaction volume or one of the N additional reaction volumes.

[0019] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0021] FIG. 1 is a functional block diagram of a first reaction volume according to the prior art;

[0022] FIG. 2 is a flowchart illustrating operation of the first reaction volume according to the prior art;

[0023] FIG. 3 is a functional block diagram of first and second reaction volumes according to the present disclosure;

[0024] FIG. 4 is a functional block diagram of three or more cascaded reaction volumes according to the present disclosure;

[0025] FIG. 5 is a functional block diagram of a controller according to the present disclosure;

[0026] FIG. 6 is a flowchart illustrating a method for operating the first and second reaction volumes of FIG. 3;

[0027] FIG. 7 is a functional block diagram of another arrangement of first and second reaction volumes according to the present disclosure;

[0028] FIG. 8 is a functional block diagram of another controller according to the present disclosure;

[0029] FIG. 9 is a flowchart illustrating a method for operating the first and second reaction volumes of FIG. 7.

[0030] FIG. 10 is a functional block diagram of another arrangement of reaction volumes according to the present disclosure; and

[0031] FIG. 11 is a flowchart illustrating a method for operating the reaction volumes of FIG. 10.

DETAILED DESCRIPTION

[0032] According to the present disclosure, a substrate is exposed to a precursor gas in a first reaction volume at a first target pressure. The substrate is allowed to soak in the precursor gas. Then, a valve is opened from the first reaction volume to a second reaction volume (or a storage volume) that is evacuated and at lower pressure than the first target pressure. After equalizing pressure, the valve is closed and precursor gas is added to the second reaction volume to achieve a second target pressure, which may or may not be the same as the first target pressure.

[0033] Referring now to FIG. 3, a first reaction volume 40 is shown. A pedestal 42 is arranged in the first reaction volume 40 and provides support for a substrate 44 such as a semiconductor wafer. A pressure sensor 45 may be arranged in the first reaction volume 40 to monitor pressure. A second reaction volume 46 is also shown. A pedestal 48 is arranged in the second reaction volume 46 and provides support for a substrate 50 such as a semiconductor wafer. A pressure sensor 51 may be arranged in the second process volume 46 to monitor pressure. Alternately, the pressure sensors 45 and 51 may be omitted and timers may be used to estimate pressure based on timing and/or other parameters.

[0034] Precursor gases 60-1, 60-2, ..., and 60-N (collectively precursor gases 60) are selectively supplied via valves 62-1, 62-2, ..., and 62-N (collectively valves 62) to the first reaction volume 40. Purge gas 64 is supplied via a valve 66 to the first reaction volume 40. A pump 68 and valve 69 may be used to selectively draw precursor and/or purge gas from the first reaction volume 40.

[0035] Precursor gases 70-1, 70-2 and 70-N (collectively precursor gases 70) are selectively supplied via valves 72-1, 72-2, ..., and 72-N (collectively valves 72) to the second reaction volume 46. Purge gas 74 is selectively supplied via a valve 76 to the second reaction volume 46. A pump 78 and valves 79 may be used to selectively draw precursor and/or purge gas from the second reaction volume 46.

[0036] As will be described further below, the substrate 44 is exposed to the precursor gas in the first reaction volume 40. The substrate 44 is allowed to soak in the precursor gas at a first target pressure. Then, a valve 79 is opened between the first reaction volume 40 and the second reaction volume 46. Before opening the valve 79, the second reaction volume 46 is evacuated and maintained at lower pressure than the first reaction volume 40. After equalizing pressure, precursor gas is added to the second reaction volume 46 to achieve a second target pressure, which may or may not be the same as the first target pressure. The substrate 50 is allowed to soak. As can be appreciated, the precursor gas may be purged and dumped or reused in the reaction volume 40.

[0037] While FIG. 3 shows first and second reaction volumes 40 and 46, three or more cascaded reaction volumes may be used. Referring now to FIG. 4, a system 80 including three or more cascaded reaction volumes 82-1, 82-2 and 82-M is shown where M is an integer greater than two. In addition, while one reaction volume is shown for each processing chamber, each processing chamber may be associated with one or more reaction volumes.

[0038] Referring now to FIG. 5, a controller 90 that may be used to control a process employing multiple reaction volumes is shown. The controller 90 communicates with and/or controls one or more valves (such as valves 62, 72 and 79, which are collectively identified at 92 in FIG. 5), pumps (such as pumps 68 and 78, which are collectively identified at 94 in FIG. 5) and/or pressure sensors (such as pressure sensors 45 and 51, which are collectively identified at 96 in FIG. 5).

[0039] Referring now to FIG. 6, an example of a method 100 for operating a controller for the first and second reaction volumes of FIG. 3 is shown. At 104, the first reaction volume is pressurized with a precursor gas to a first target pressure. At 108, the substrate is allowed to soak for a predetermined period. At 112, the second reaction volume is evacuated to a pressure lower than the first reaction volume. At 116, the valve 79 is opened. At 120, a predetermined period is timed to allow pressure equilibrium to occur. As used herein, equilibrium refers to equal or substantially equal pressures. In some examples, substantially equal pressures refer to pressures within 10%, 5%, 2%, 1% or less of each other. The equilibrium pressure will be lower than the target soak pressure in the second reaction volume. If the volumes are equal, then the equilibrium pressure will be approximately half the target pressure assuming that the process volumes are equal.

[0040] At 124, the valve 79 is closed. At 128, additional precursor gas is introduced into the second reaction volume to achieve a second target pressure. At 132, residual precursor gas in the first reaction volume may be dumped. A substrate is allowed to soak in the second reaction volume. At 136, the precursor gas in the second reaction volume may be purged and dumped or cascaded to additional reaction volumes if desired.

[0041] Referring now to FIGs. 7-8, another arrangement of first and second reaction volumes is shown. A compressor 150 is arranged between a valve 151 (that is connected to the first reaction volume 40) and a value (that is connected to the second reaction volume 46). In FIG. 8, the controller 90 may be further connected to the compressor 150.

[0042] Referring now to FIG. 9, an example of a method 200 for operating a controller for the first and second reaction volumes of FIG. 7 is shown. At 204, the first reaction volume is pressurized with a precursor gas to a first target pressure. At 208, the substrate is allowed to soak in the precursor gas for a predetermined period. At 212, the second reaction volume is evacuated to a pressure lower than the first reaction volume. At 216, the valves 151 and 152 are opened to the compressor 150. The compressor 150 compresses the precursor with added energy in order to drive it into the second reaction volume 46.

[0043] Pressurization of the second reaction volume will follow a first order exponential response curve. In addition, due to the thermodynamic losses due to compression, the steady state maximum achievable pressure will be lower than the target pressure for the second reaction volume, but higher than the pressure provided by the process described in FIGs. 3 and 6.

[0044] At 220, the valves 151 and 152 are closed. At 224, additional precursor gas is introduced into the second reaction volume to achieve a second target pressure. At 228, residual precursor gas in the first reaction volume may be dumped. The substrate in the second reaction volume is allowed to soak. At 232, the precursor gas in the second reaction volume may be cascaded to additional reaction volumes if desired.

[0045] Examples of reaction volumes include but are not limited to substrate processing chambers or stations of substrate processing chambers. Examples of processes include, but are not limited to, conformal film deposition, atomic layer deposition, plasma-enhanced atomic layer deposition, and dielectric constant (k) recovery processes. The pedestals may be temperature controlled and/or biased by an RF bias. While the processes described above include a soak step, additional operations may be performed.

[0046] Referring now to FIG. 10, another substrate processing system 300 is shown. Process gases 304-1, 304-2, …, and 304-T are selectively supplied to reaction volumes 310-1, 310-2, …, and 310-T via valves 306-1, 306-2, …, and

306T, respectively. Pressure sensors 312-1 312-2, ..., and 312-T monitor pressure in the reaction volumes 310-1, 310-2, ..., 310-T, respectively. The reaction volumes 310-1, 310-2, ..., and 310-T can be evacuated using valves 318-1, 318-2, ..., and 318-T and pumps 320-1, 320-2, ..., and 320-T, respectively. Valves 324-1, 324-2, ..., and 324-T, a compressor 326 and a second valve 330 are connected between the reaction volumes 310-1, 310-2, ..., and 310-T, respectively, and a storage volume 334. The storage volume 334 can be evacuated using a valve 338 and a pump 340.

[0047] A controller 350 communicates with the pressure sensors 312 and 336, the pumps 318 and 338, the valves 318, 324, 330 and 338 and the compressor 326. The controller 350 pressurizes the reaction volume of the reaction volume 310-1 with precursor to a first target pressure. The controller 350 waits a predetermined soak period. The controller 350 evacuates the storage volume 334 to a pressure that is lower than the first target pressure. The controller 350 opens the valves 324-1 and 330 between the reaction volume 310-1 and the storage volume 334. The controller 350 operates the compressor 326 to pump the precursor gas from the reaction volume 310-1 to the storage volume 334.

[0048] The controller 350 closes the valves 324-1 and 330. The controller 350 may purge residual precursor from the first reaction volume. The controller 350 may open any one of the valves 324-1, 324-2, ..., and 324-T and the value 330 between one of the reaction volumes 310-1, 310-2, ..., and 310-T and the storage volume 334 and operates the compressor 326 to pump the precursor from the storage volume 334 back to the one of the reaction volumes 310-1, 310-2, ..., and 310-T. Additional precursor gas may be added to the selected reaction volume as described above.

[0049] As can be appreciated, T processing chambers can be connected to S storage volumes, where T and S are integers and T >= S. For example in FIG. 10, T processing chambers may be connected to 1 storage volume that is shared. The precursor gas can be returned to the same processing chamber or a different processing chamber.

[0050] Referring now to FIG. 11, an example of a method 400 for operating the reaction volumes and storage volume of FIG. 10 is shown. At 404, the first reaction volume is pressurized with a precursor gas to a first target pressure. At 408, the substrate is allowed to soak in the precursor gas for a predetermined period. At 412, the storage volume is evacuated to a pressure lower than the first reaction volume. At 416, the valves are opened and the compressor is operated. The compressor compresses the precursor with added energy in order to drive it into the storage volume.

[0051] At 420, control closes the valves. At 428, residual precursor gas in the first reaction volume may be dumped. One or more operations may be performed in the first reaction volume. At 432, the valves are opened from the storage volume to the first reaction volume or any of the other reaction volumes and the compressor is operated to deliver the precursor gas to the selected reaction volume.

[0052] The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical OR. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

[0053] As used herein, the term controller may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC); an electronic circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip. The term controller may include memory (shared, dedicated, or group) that stores code executed by the processor.

[0054] The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, and/or objects. The term shared, as used above, means that some or all code from multiple controllers may be executed using a single (shared) processor. In addition, some or all code from multiple controllers may be stored by a single (shared) memory. The term group, as used above, means that some or all code from a single controller may be executed using a group of processors. In addition, some or all code from a single controller may be stored using a group of memories.

[0055] The apparatuses and methods described herein may be implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on a non-transitory tangible computer readable medium. The computer programs may also include stored data. Non-limiting examples of the non-transitory tangible computer readable medium are nonvolatile memory, magnetic storage, and optical storage.

CLAIMS

What is claimed is:

1. A substrate processing system comprising:

one or more processing chambers defining N reaction volumes, wherein N is an integer greater than one;

N-1 first valves arranged between the N reaction volumes;

a controller in communication with the N-1 first valves and configured to:

pressurize a first one of the N reaction volumes with precursor gas to a first target pressure;

wait a first predetermined soak period;

evacuate a second one of the N reaction volumes to a second target pressure that is lower than the first target pressure; and

open one of the N-1 first valves between the first one of the N reaction volumes and a second one of the N reaction volumes.

2. The substrate processing system of claim 1, further comprising N pressure sensors that measure pressure in the N reaction volumes, respectfully, wherein the controller is configured to communicate with the N pressure sensors.

3. The substrate processing system of claim 1, further comprising N pumps in fluid communication with the N reaction volumes via N second valves, wherein the controller is configured to selectively operate the N pumps and the N second valves.

4. The substrate processing system of claim 1, wherein the controller is configured to:

wait until a predetermined pressure relationship exists between the first one of the N reaction volumes and the second one of the N reaction volumes; and

close the one of the N-1 first valves.

5. The substrate processing system of claim 4, wherein the predetermined pressure relationship is pressure equilibrium.

6. The substrate processing system of claim 4, wherein the controller is configured to introduce an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure after closing the one of the N-1 first valves.

7. The substrate processing system of claim 4, wherein the controller is configured to purge residual precursor gas from the first one of the N reaction volumes.

8. The substrate processing system of claim 6, wherein the controller is configured to:

wait a second predetermined soak period; and

cascade the precursor gas in the second one of the N reaction volumes to an additional one of the N reaction volumes.

9. The substrate processing system of claim 1, further comprising:

N-1 compressors and N-1 second valves arranged between the N reaction volumes,

wherein the controller is further in communication with the N-1 compressors and the N-1 second valves, and

wherein the controller is configured to:

after evacuating the second one of the N reaction volumes to the second target pressure, open one of the N-1 second valves between the first one of the N reaction volumes and the second one of the N reaction volumes; and

operate one of the N-1 compressors to drive the precursor gas from the first one of the N reaction volumes to the second one of the N reaction volumes.

10. The substrate processing system of claim 9, wherein the controller is configured to close the one of the N-1 first valves and the one of the N-1 second valves.

11. The substrate processing system of claim 10, wherein the controller is configured to add an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure.

12. The substrate processing system of claim 10, wherein the controller is configured to purge residual precursor from the first one of the N reaction volumes.

13. A substrate processing system comprising:

a processing chamber defining a reaction volume;

a first valve arranged between the reaction volume and a storage volume;

a controller in communication with the first valve and configured to:

pressurize the reaction volume with precursor gas to a first target pressure;

wait a predetermined soak period;

evacuate the storage volume to a pressure that is lower than the first target pressure; and

open the first valve.

14. The substrate processing system of claim 13, further comprising:

a second valve arranged between the first valve and the storage volume; and

a compressor arranged between the first valve and the second valve,

wherein the controller communicates with the second valve and the compressor and is configured to operate the first valve, the second valve and the compressor to drive the precursor gas from the reaction volume to the storage volume

15. The substrate processing system of claim 13, further comprising:

a pressure sensor that measures pressure in the reaction volume; and

a pump in fluid communication with the reaction volume via a second valve,

wherein the controller communicates with the pressure sensor, the pump and the second valve.

16. The substrate processing system of claim 14, wherein the controller is configured to close the first valve and the second valve.

17. The substrate processing system of claim 14, wherein the controller is configured to purge residual precursor from the reaction volume.

18. The substrate processing system of claim 17, wherein the controller is configured to:

open the first valve and the second valve between the reaction volume and the storage volume; and

operate the compressor to drive the precursor gas from the storage volume to the reaction volume.

19. The substrate processing system of claim 14, further comprising:

N additional reaction volumes;

N additional valves connecting the N additional reaction volumes to the compressor,

wherein the controller is configured to:

open one of the first valve or one of the N additional valves,

open the second valve; and

operate the compressor to pump the precursor gas from the storage volume to one of the reaction volume or one of the N additional reaction volumes.

20. A method comprising:

pressurizing a first one of N reaction volumes with precursor gas to a first target pressure;

waiting a first predetermined soak period;

evacuating a second one of the N reaction volumes to a second target pressure that is lower than the first target pressure; and

opening one of N-1 first valves between the first one of the N reaction volumes and a second one of the N reaction volumes.

21. The method of claim 20, further comprising:

waiting until a predetermined pressure relationship occurs between the first one of the N reaction volumes and the second one of the N reaction volumes; and

closing the first one of the N-1 first valves.

22. The method of claim 21, wherein the predetermined pressure relationship is pressure equilibrium.

23. The method of claim 21, further comprising introducing an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure after closing the first one of the N-1 first valves.

24. The method of claim 21, further comprising purging residual precursor gas from the first reaction volume.

25. The method of claim 23, further comprising:

waiting a second predetermined soak period; and

cascading the precursor gas to an additional one of the N reaction volumes.

26. The method of claim 20, further comprising:

arranging N-1 compressors and N-1 second valves between the N reaction volumes;

after evacuating the second one of the N reaction volumes to the second target, opening one of the N-1 second valves between the first one of the N reaction volumes and the second one of the N reaction volumes; and

operating one of the N-1 compressors to drive the precursor gas from the first one of the N reaction volumes to the second one of the N reaction volumes.

27. The method of claim 26, further comprising closing the one of the N-1 first valves and the one of the N-1 second valves.

28. The method of claim 27, further comprising adding an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure.

29. The method of claim 27, further comprising purging residual precursor gas from the first one of the N reaction volumes.

30. A method of operating a substrate processing system comprising:

pressurizing a reaction volume with precursor gas to a first target pressure;

waiting a predetermined soak period;

evacuating a storage volume to a pressure that is lower than the first target pressure; and

opening a first valve located between the reaction volume and the storage volume.

31. The method of claim 30, further comprising:

arranging a compressor and a second valve between the first valve and the storage volume;

opening the second valve; and

operating the compressor to drive the precursor gas from the reaction volume to the storage volume.

32. The method of claim 31, further comprising closing the first valve and the second valve.

33. The method of claim 30, further comprising purging residual precursor gas from the reaction volume.

34. The method of claim 31, further comprising:

opening the first valve and the second valve between the reaction volume and the storage volume; and

operating the compressor to drive the precursor gas from the storage volume to the reaction volume.

35. The method of claim 31, further comprising:

arranging N additional valves to connect N additional reaction volumes to the compressor;

opening the first valve or one of the N additional valves;

opening the second valve; and

operating the compressor to pump the precursor gas from the storage volume to one of the reaction volume or one of the N additional reaction volumes.

AMENDED CLAIMS
received by the International Bureau on 08 August 2013.

What is claimed is:

1. A substrate processing system comprising:

one or more processing chambers defining N reaction volumes, wherein N is an integer greater than one;

N-1 first valves arranged between the N reaction volumes; and

a controller in communication with the N-1 first valves and configured to:

pressurize a first one of the N reaction volumes with precursor gas to a first target pressure;

wait a first predetermined soak period;

evacuate a second one of the N reaction volumes to a second target pressure that is lower than the first target pressure;

open one of the N-1 first valves between the first one of the N reaction volumes and a second one of the N reaction volumes;

close the one of the N-1 first valves subsequent to the opening of the one of the N-1 first valves; and

introduce an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure after the closing of the one of the N-1 first valves.

2. The substrate processing system of claim 1, further comprising N pressure sensors that measure pressure in the N reaction volumes, respectively, wherein the controller is configured to communicate with the N pressure sensors.

3. The substrate processing system of claim 1, further comprising N pumps in fluid communication with the N reaction volumes via N second valves, wherein the controller is configured to selectively operate the N pumps and the N second valves.

4. The substrate processing system of claim 1, wherein the controller is configured to:

wait until a predetermined pressure relationship exists between the first one of the N reaction volumes and the second one of the N reaction volumes; and

perform the closing of the one of the N-1 first valves in response to the predetermined pressure relationship existing between the first one of the N reaction volumes and the second one of the N reaction volumes.

5. The substrate processing system of claim 4, wherein the predetermined pressure relationship is pressure equilibrium.

6. The substrate processing system of claim 4, wherein the controller is configured to purge residual precursor gas from the first one of the N reaction volumes.

7. The substrate processing system of claim 1, wherein the controller is configured to:

wait a second predetermined soak period; and

cascade the precursor gas in the second one of the N reaction volumes to an additional one of the N reaction volumes.

8. The substrate processing system of claim 1, further comprising N-1 compressors and N-1 second valves arranged between the N reaction volumes, wherein:

the controller is further in communication with the N-1 compressors and the N-1 second valves; and

the controller is configured to:

after evacuating the second one of the N reaction volumes to the second target pressure, open one of the N-1 second valves between the first one of the N reaction volumes and the second one of the N reaction volumes; and

operate one of the N-1 compressors to drive the precursor gas from the first one of the N reaction volumes to the second one of the N reaction volumes.

9. The substrate processing system of claim 8, wherein the controller is configured to close the one of the N-1 first valves and the one of the N-1 second valves.

10. The substrate processing system of claim 9, wherein the controller is configured to add an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure.

11. The substrate processing system of claim 9, wherein the controller is configured to purge residual precursor from the first one of the N reaction volumes.

12. A substrate processing system comprising:

a processing chamber defining a reaction volume;

a first valve arranged between the reaction volume and a storage volume;

a controller in communication with the first valve and configured to:

pressurize the reaction volume with precursor gas to a first target pressure;

wait a predetermined soak period;

evacuate the storage volume to a pressure that is lower than the first target pressure; and

open the first valve;

a second valve arranged between the first valve and the storage volume; and

a compressor arranged between the first valve and the second valve,

wherein the controller communicates with the second valve and the compressor and is configured to operate the first valve, the second valve and the compressor to drive the precursor gas from the reaction volume to the storage volume.

13. The substrate processing system of claim 12, further comprising:

a pressure sensor that measures pressure in the reaction volume; and

a pump in fluid communication with the reaction volume via a third valve, wherein the controller communicates with the pressure sensor, the pump and the third valve.

14. The substrate processing system of claim 12, wherein the controller is configured to close the first valve and the second valve.

15. The substrate processing system of claim 12, wherein the controller is configured to purge residual precursor from the reaction volume.

16. The substrate processing system of claim 15, wherein the controller is configured to:

open the first valve and the second valve between the reaction volume and the storage volume; and

operate the compressor to drive the precursor gas from the storage volume to the reaction volume.

17. The substrate processing system of claim 12, further comprising:

N additional reaction volumes;

N additional valves connecting the N additional reaction volumes to the compressor,

wherein the controller is configured to:

open one of the first valve or one of the N additional valves;

open the second valve; and

operate the compressor to pump the precursor gas from the storage volume to one of the reaction volume or one of the N additional reaction volumes.

18. A method comprising:

pressurizing a first one of N reaction volumes with precursor gas to a first target pressure;

waiting a first predetermined soak period;

evacuating a second one of the N reaction volumes to a second target pressure that is lower than the first target pressure;

opening one of N-1 first valves between the first one of the N reaction volumes and a second one of the N reaction volumes;

after evacuating the second one of the N reaction volumes to the second target, opening one of N-1 second valves between the first one of the N reaction volumes and the second one of the N reaction volumes; and

operating one of N-1 compressors between the N reaction volumes to drive the precursor gas from the first one of the N reaction volumes to the second one of the N reaction volumes.

19. The method of claim 18, further comprising:

waiting until a predetermined pressure relationship occurs between the first one of the N reaction volumes and the second one of the N reaction volumes; and

closing the first one of the N-1 first valves.

20. The method of claim 19, wherein the predetermined pressure relationship is pressure equilibrium.

21. The method of claim 19, further comprising introducing an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure after closing the first one of the N-1 first valves.

22. The method of claim 19, further comprising purging residual precursor gas from the first reaction volume.

23. The method of claim 21, further comprising:

waiting a second predetermined soak period; and

cascading the precursor gas to an additional one of the N reaction volumes.

24. The method of claim 18, further comprising closing the one of the N-1 first valves and the one of the N-1 second valves.

25. The method of claim 24, further comprising adding an additional amount of the precursor gas to the second one of the N reaction volumes to achieve a third target pressure.

26. The method of claim 24, further comprising purging residual precursor gas from the first one of the N reaction volumes.

27. A method of operating a substrate processing system comprising:

pressurizing a reaction volume with precursor gas to a first target pressure;

waiting a predetermined soak period;

evacuating a storage volume to a pressure that is lower than the first target pressure;

opening a first valve located between the reaction volume and the storage volume;

opening a second valve between the first valve and the storage volume; and

operating a compressor between the first valve and the storage volume to drive the precursor gas from the reaction volume to the storage volume.

28. The method of claim 27, further comprising closing the first valve and the second valve.

29. The method of claim 27, further comprising purging residual precursor gas from the reaction volume.

30. The method of claim 27, further comprising:

opening the first valve and the second valve between the reaction volume and the storage volume; and

operating the compressor to drive the precursor gas from the storage volume to the reaction volume.

31. The method of claim 27, further comprising:

opening the first valve or one of N additional valves, wherein the N additional valves connect N additional reaction volumes to the compressor;

opening the second valve; and

operating the compressor to pump the precursor gas from the storage volume to one of the reaction volume or one of the N additional reaction volumes.

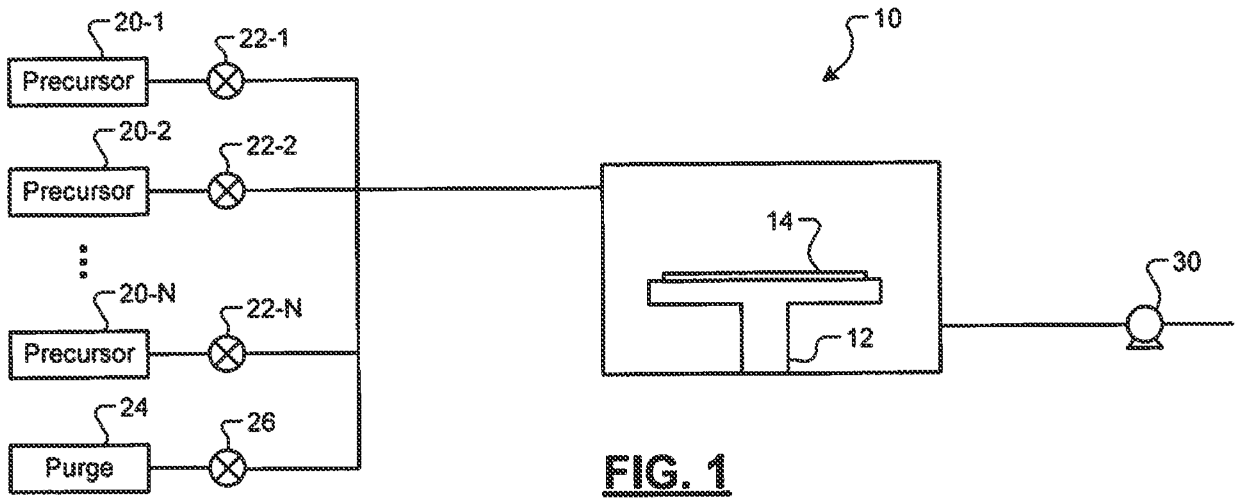


FIG. 1
Prior Art

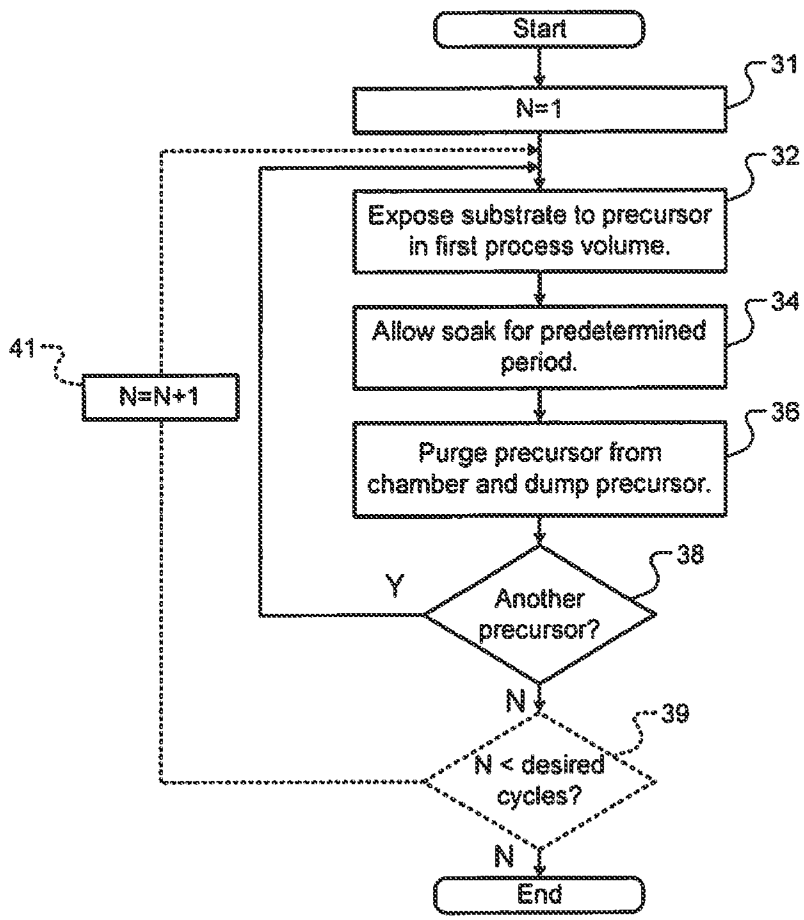


FIG. 2
Prior Art

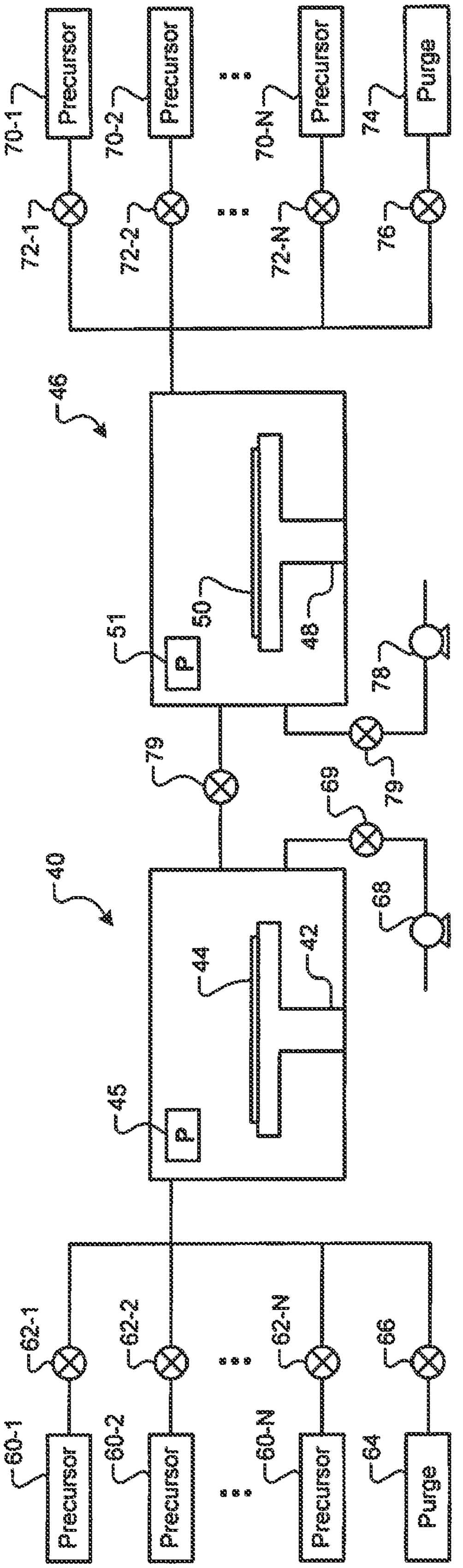


FIG. 3

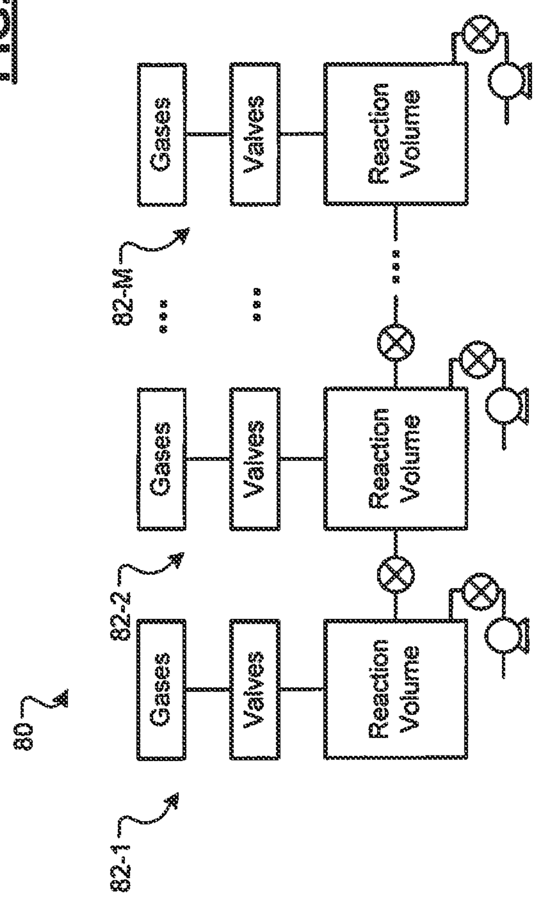


FIG. 4

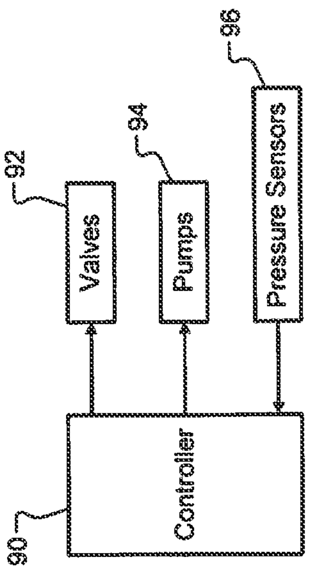


FIG. 5

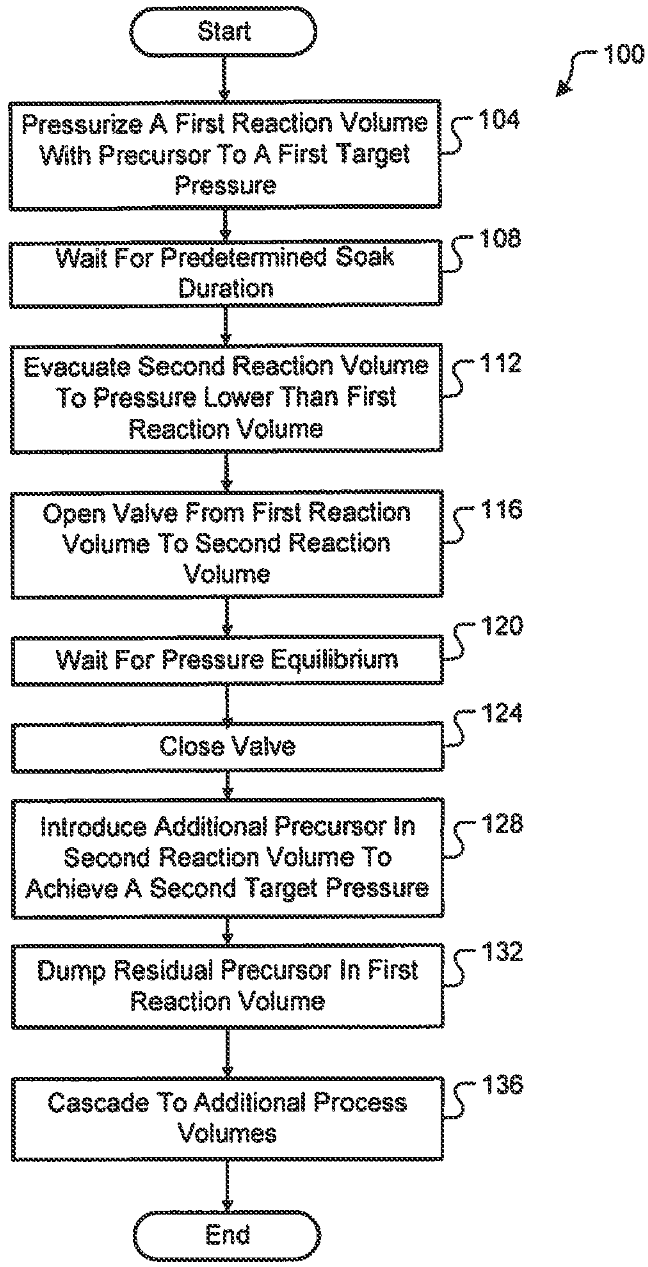
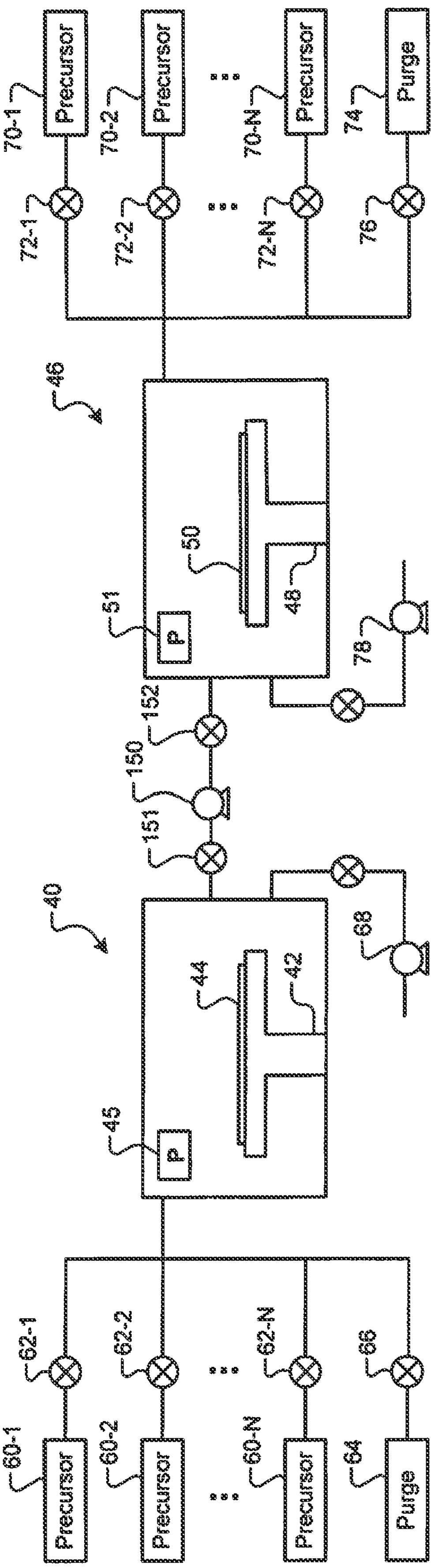

Start
100
Pressurize A First Reaction Volume With Precursor To A First Target Pressure
104
Wait For Predetermined Soak Duration
108
Evacuate Second Reaction Volume To Pressure Lower Than First Reaction Volume
112
Open Valve From First Reaction Volume To Second Reaction Volume
116
Wait For Pressure Equilibrium
120
Close Valve
124
Introduce Additional Precursor In Second Reaction Volume To Achieve A Second Target Pressure
128
Dump Residual Precursor In First Reaction Volume
132
Cascade To Additional Process Volumes
136
End

FIG. 6

FIG. 7


Precursor
60-1
Precursor
60-2
Precursor
60-N
Purge
64
62-1
62-2
62-N
66
40
45
P
44
42
68
151
150
152
46
51
P
50
48
78
72-1
72-2
72-N
76
70-1
Precursor
70-2
Precursor
70-N
Precursor
74
Purge

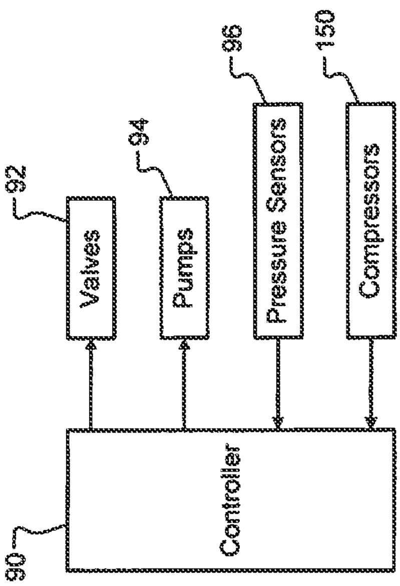

90
Controller
92
Valves
94
Pumps
96
Pressure Sensors
150
Compressors

FIG. 8

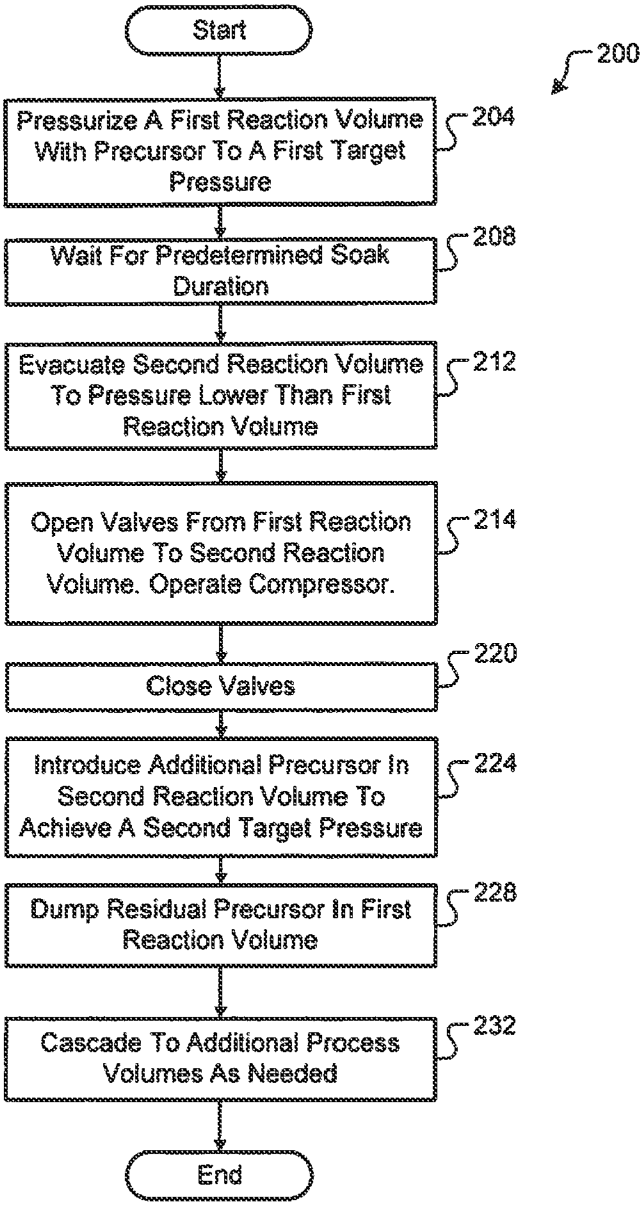

Start
200
Pressurize A First Reaction Volume With Precursor To A First Target Pressure
204
Wait For Predetermined Soak Duration
208
Evacuate Second Reaction Volume To Pressure Lower Than First Reaction Volume
212
Open Valves From First Reaction Volume To Second Reaction Volume. Operate Compressor.
214
Close Valves
220
Introduce Additional Precursor In Second Reaction Volume To Achieve A Second Target Pressure
224
Dump Residual Precursor In First Reaction Volume
228
Cascade To Additional Process Volumes As Needed
232
End

FIG. 9

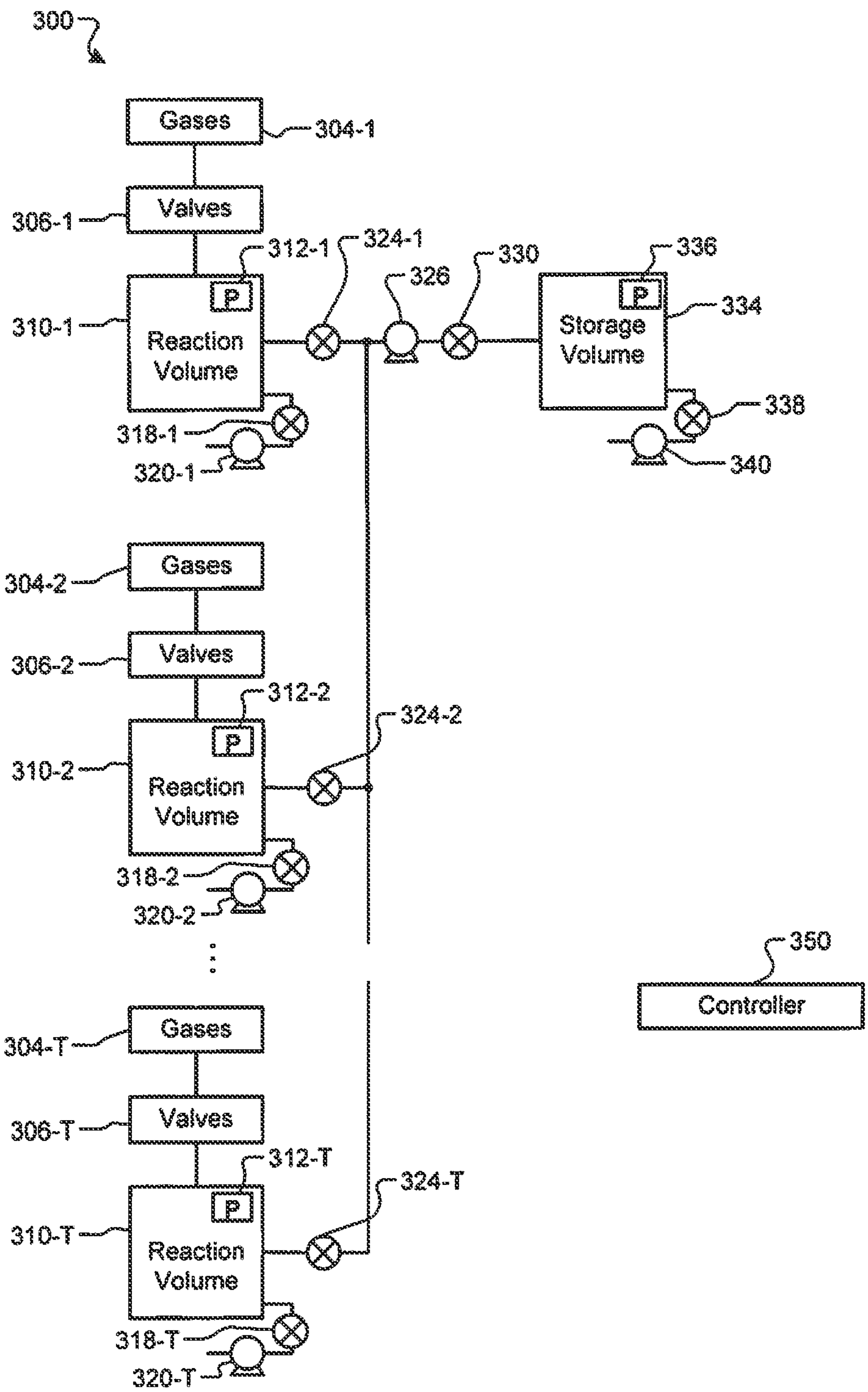

300
Gases
304-1
Valves
306-1
312-1
324-1
326
330
336
P
Reaction Volume
310-1
Storage Volume
334
318-1
320-1
338
340
Gases
304-2
Valves
306-2
312-2
324-2
310-2
Reaction Volume
318-2
320-2
350
Controller
Gases
304-T
Valves
306-T
312-T
324-T
310-T
Reaction Volume
318-T
320-T

FIG. 10

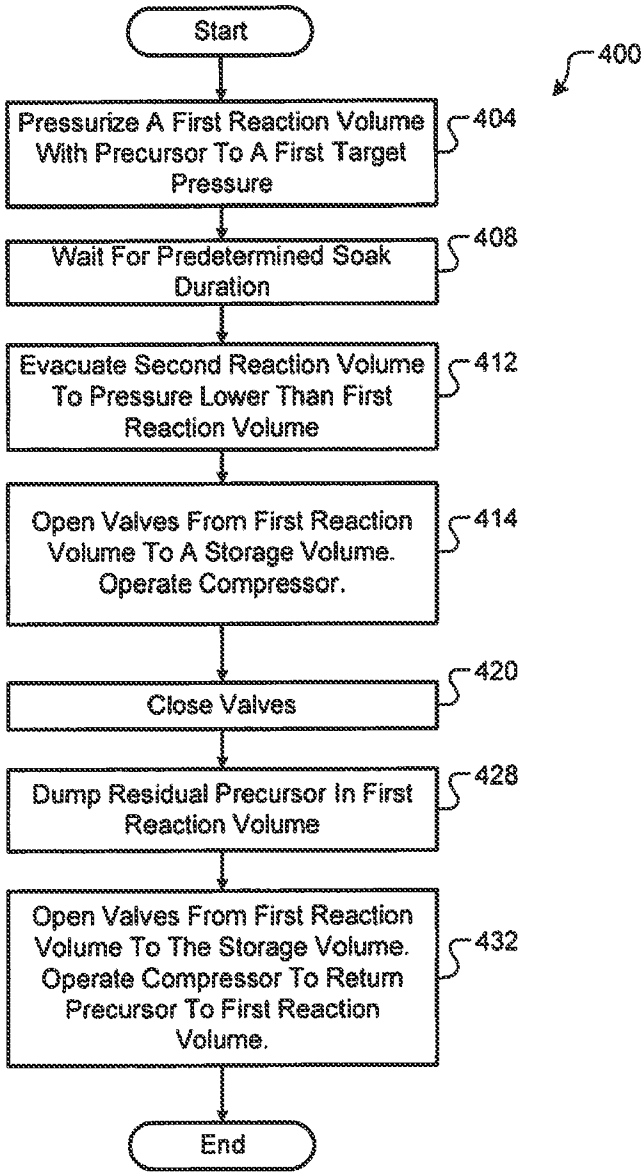

Start
400
Pressurize A First Reaction Volume With Precursor To A First Target Pressure
404
Wait For Predetermined Soak Duration
408
Evacuate Second Reaction Volume To Pressure Lower Than First Reaction Volume
412
Open Valves From First Reaction Volume To A Storage Volume. Operate Compressor.
414
Close Valves
420
Dump Residual Precursor In First Reaction Volume
428
Open Valves From First Reaction Volume To The Storage Volume. Operate Compressor To Return Precursor To First Reaction Volume.
432
End

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/028214

A. CLASSIFICATION OF SUBJECT MATTER

H01L 21/205(2006.01)i

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)
H01L 21/205; H01L 21/68; H01L 21/3065; H01L 21/027; G06F 19/00; H01L 21/677; B65G 49/00; G03F 7/20; H01L 21/465

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: chamber, press, equal, valve, control, reuse

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2002-270663 A (DAIKIN IND LTD.) 20 September 2002 See paragraphs [0007]-[0022], claim 1 and figure 1.	1,3-5,7,20-22,24
Y		2,13,15,30,33
A		6,8-12,14,16-19,23 ,25-29,31-32,34-35
Y	JP 2001-102281 A (CANON INC.) 13 April 2001 See paragraphs [0042]-[0065] and figures 1-7.	2,13,15,30,33
A	JP 2011-233707 A (NISSIN ELECTRIC CO., LTD.) 17 November 2011 See abstract, paragraphs [0013]-[0200] and figures 1-11.	1-35
A	US 2010-0256809 A1 (KENGO ASHIZAWA) 07 October 2010 See abstract, paragraphs [0063]-[0067] and figure 3.	1-35
A	US 2011-0100554 A1 (DAVID K. CARLSON et al.) 05 May 2011 See abstract, paragraphs [0025]-[0026],[0029]-[0030] and figures 1-3.	1-35

☐ 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 application or patent but 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 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
21 June 2013 (21.06.2013)

Date of mailing of the international search report
24 June 2013 (24.06.2013)

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. 82-42-472-7140

Authorized officer
CHOI, Sang Won
Telephone No. 82-42-481-8291

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2002-270663 A	20.09.2002	JP 3470701 B2	25.11.2003
JP 2001-102281 A	13.04.2001	None	
JP 2011-233707 A	17.11.2011	None	
US 2010-0256809 A1	07.10.2010	JP 2007-149948 A	14.06.2007
		JP 4634918 B2	16.02.2011
		US 2007-0119393 A1	31.05.2007
US 2011-0100554 A1	05.05.2011	TW 201117268 A	16.05.2011
		WO 2011-031672 A2	17.03.2011
		WO 2011-031672 A3	16.06.2011