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(54) METHODS AND APPARATUS FOR PROCESSING MICROFEATURE WORKPIECES, E.G., FOR DEPOSITING MATERIALS ON MICROFEATURE WORKPIECES

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(57) **ABSTRACT**

The present disclosure suggests several systems and methods for batch processing of microfeature workpieces, e.g., semiconductor wafers or the like. One exemplary implementation provides a method of depositing a reaction product on each of a batch of workpieces positioned in a process chamber in a spaced-apart relationship. A first gas may be delivered to an elongate first delivery conduit that includes a plurality of outlets spaced along a length of the conduit. A first gas flow may be directed by the outlets to flow into at least one of the process spaces between adjacent workpieces along a first vector that is transverse to the direction in which the workpieces are spaced. A second gas may be delivered to an elongate second delivery conduit that also has outlets spaced along its length. A second gas flow of the second gas may be directed by the outlets to flow into the process spaces along a second vector that is transverse to the first direction.

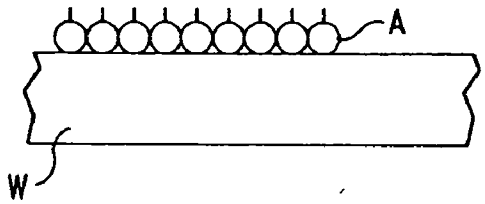


Fig. 1A
(Prior Art)

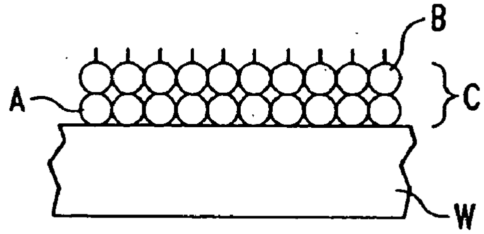


Fig. 1B
(Prior Art)

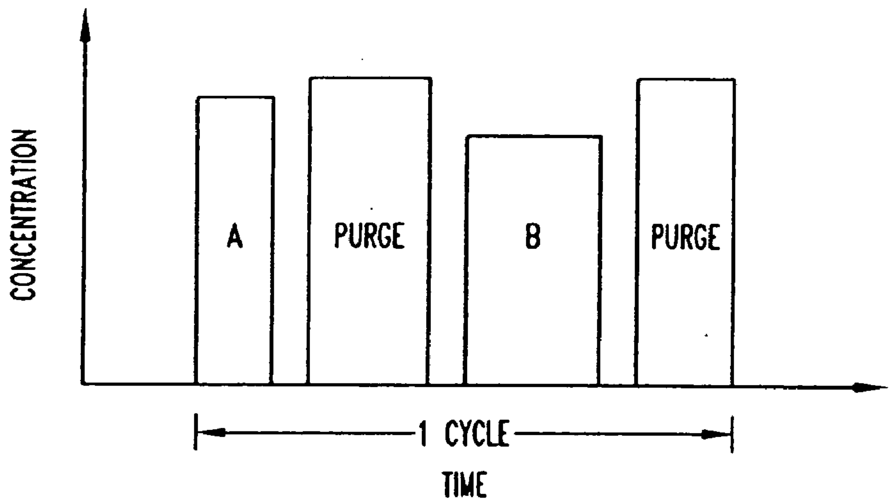


Fig. 2
(Prior Art)

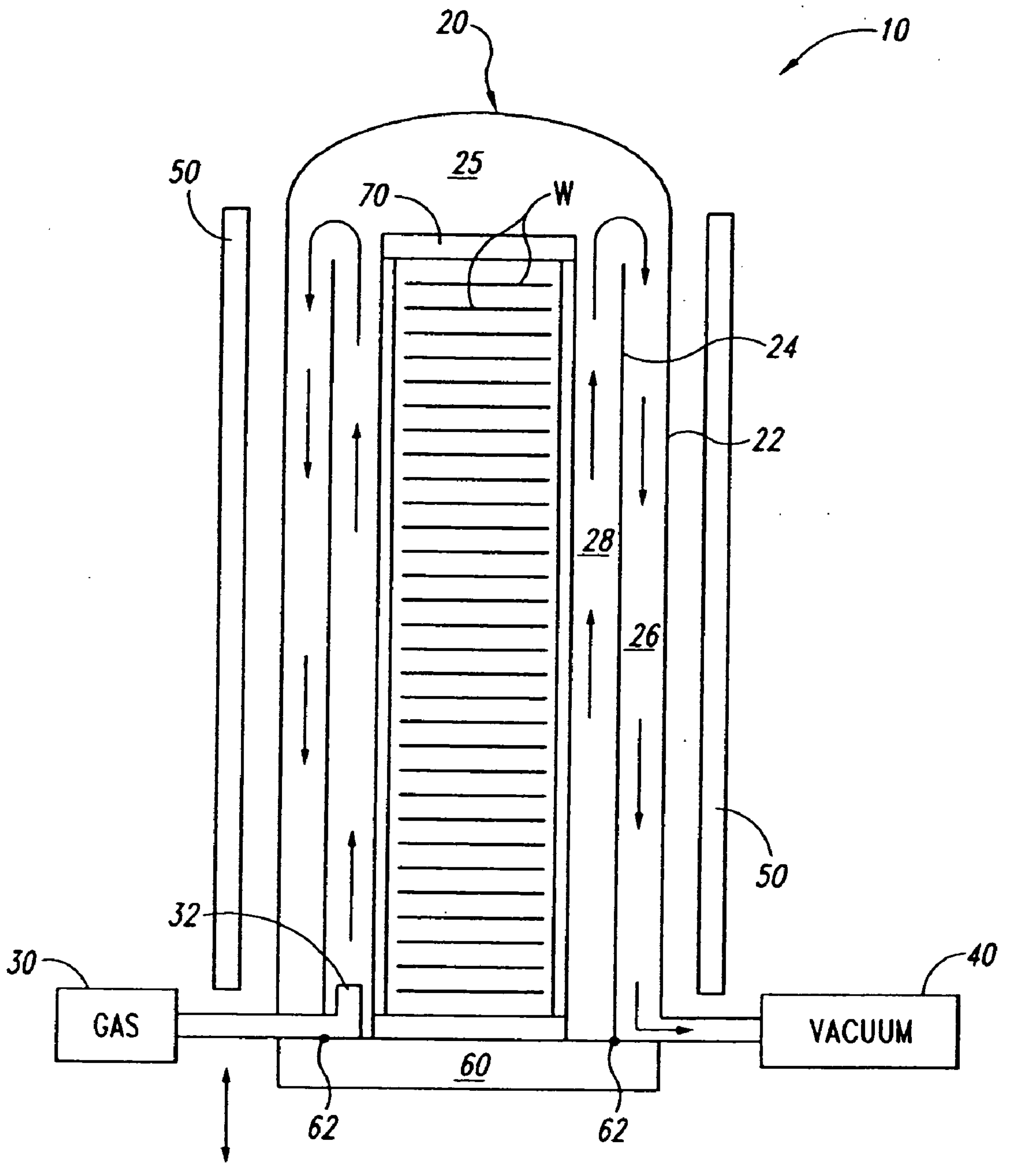


Fig. 3
(Prior Art)

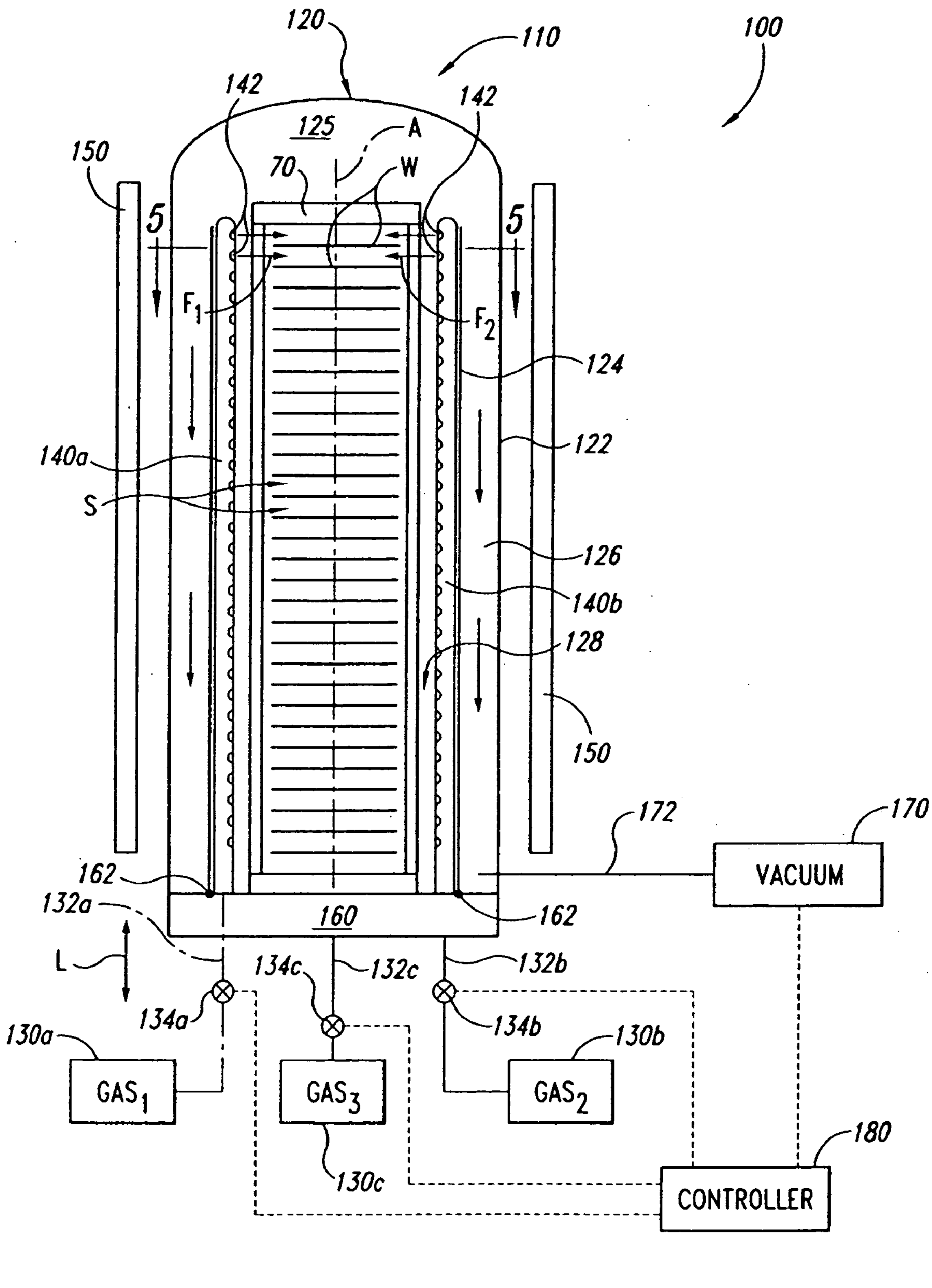

120
110
100
142
125
A
142
150
70
W
5
5
F1
F2
124
122
140a
S
126
140b
128
150
172
170
VACUUM
162
132a
160
162
L
134c
132c
132b
134a
134b
130a
130b
GAS1
GAS3
GAS2
180
130c
CONTROLLER

Fig. 4

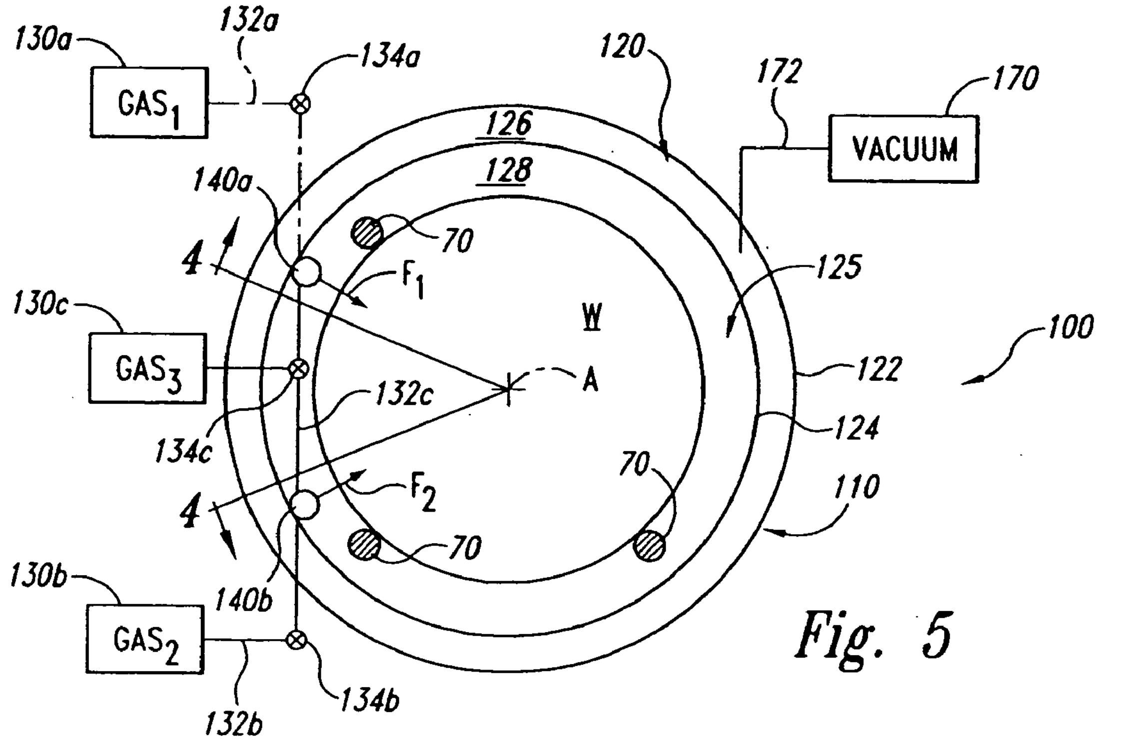

130a
132a
134a
GAS1
120
126
128
172
170
VACUUM
140a
70
4
F1
125
W
130c
GAS3
A
100
122
132c
134c
124
70
110
4
F2
70
130b
140b
GAS2
134b
132b

Fig. 5

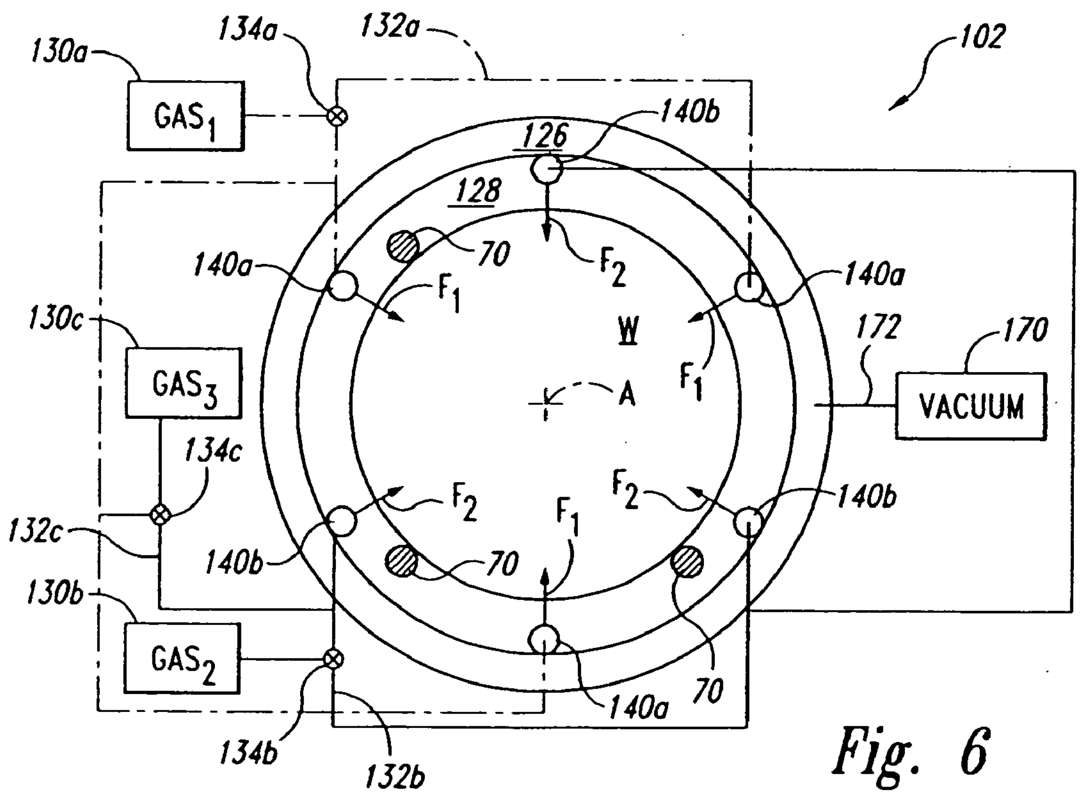
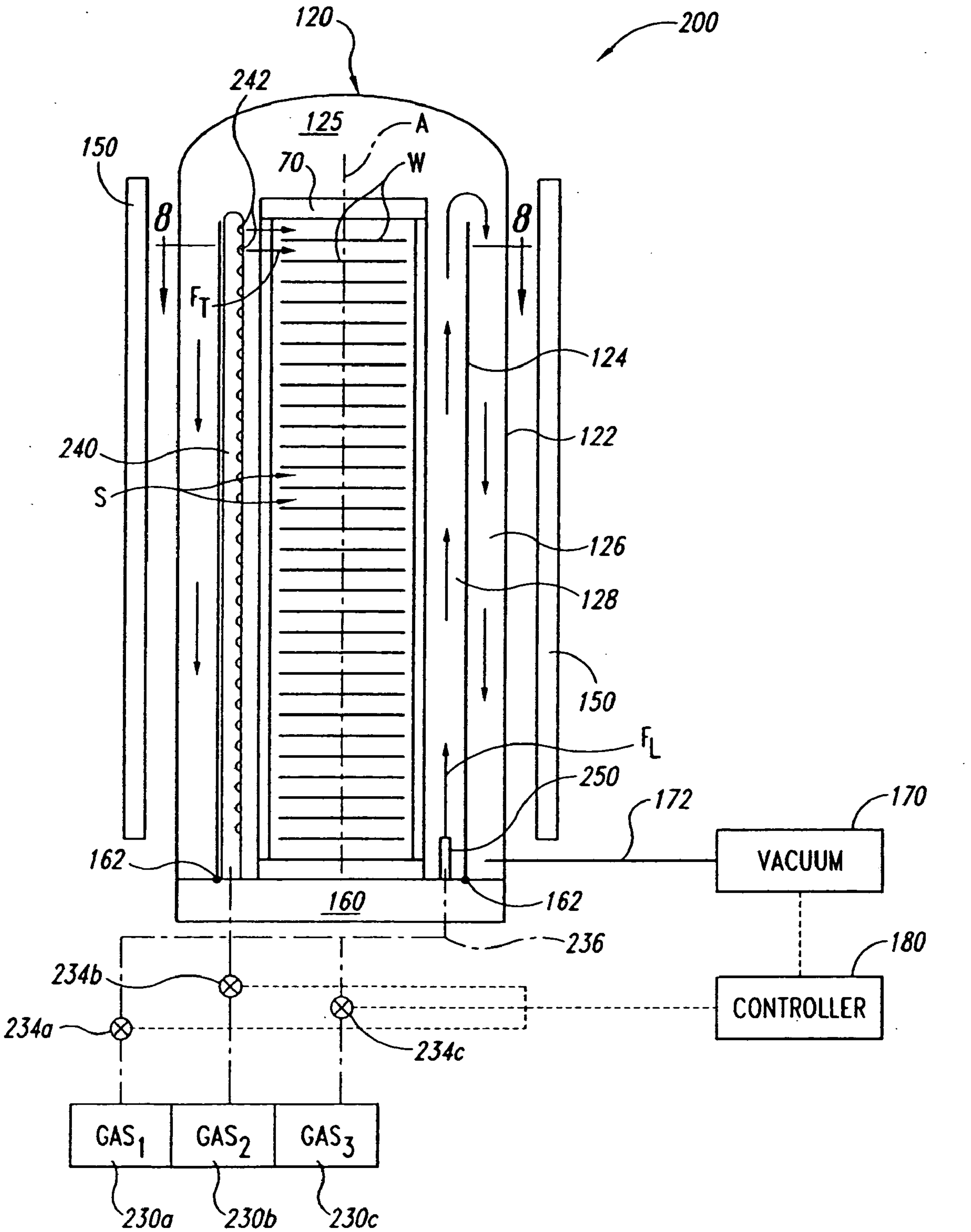

134a
132a
102
130a
GAS1
140b
126
128
70
F2
140a
140a
F1
W
130c
172
170
GAS3
F1
VACUUM
A
134c
F2
132c
F2
140b
F1
140b
70
130b
GAS2
70
140a
134b
132b

Fig. 6



120
200
242
125
A
150
70
W
8
8
F_T
124
122
240
S
126
128
150
F_L
250
172
170
VACUUM
162
162
160
236
180
234b
CONTROLLER
234a
234c
GAS_1
GAS_2
GAS_3
230a
230b
230c

Fig. 7

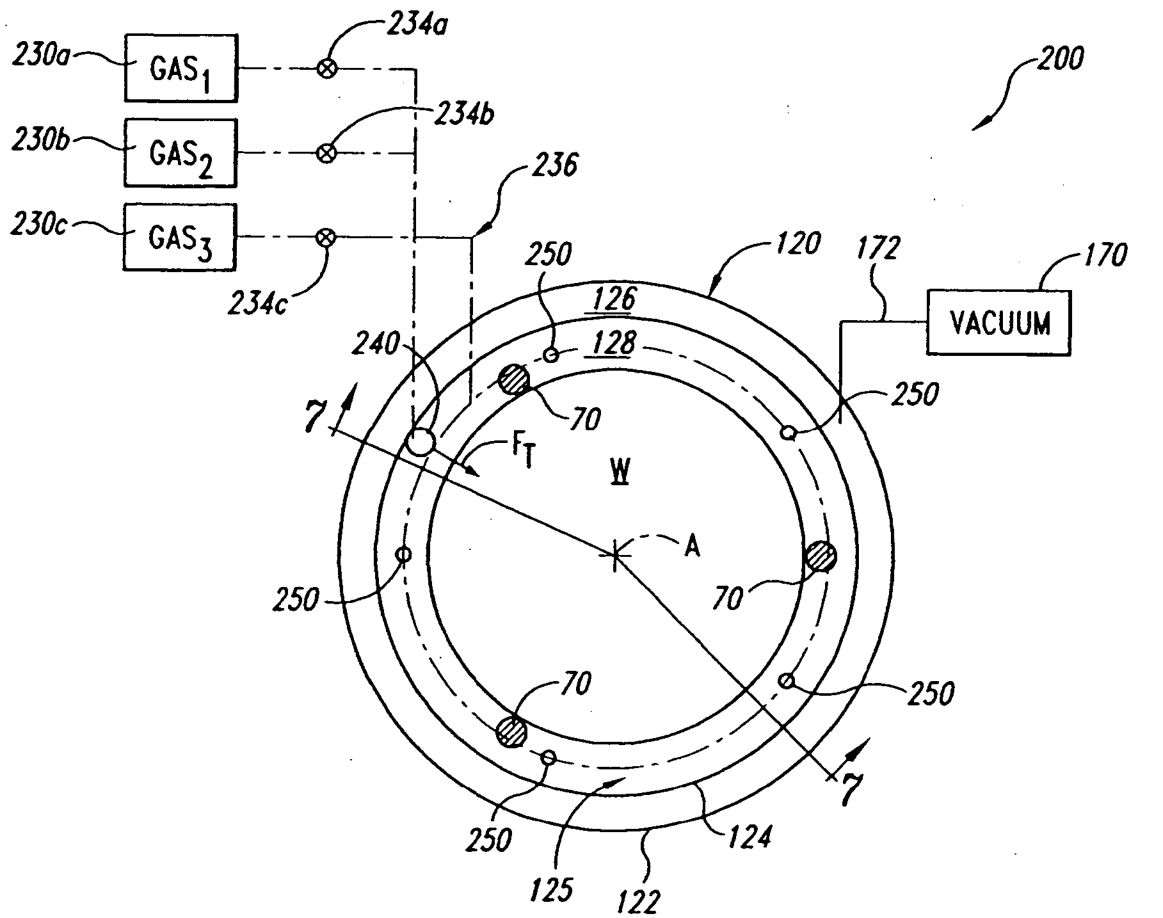
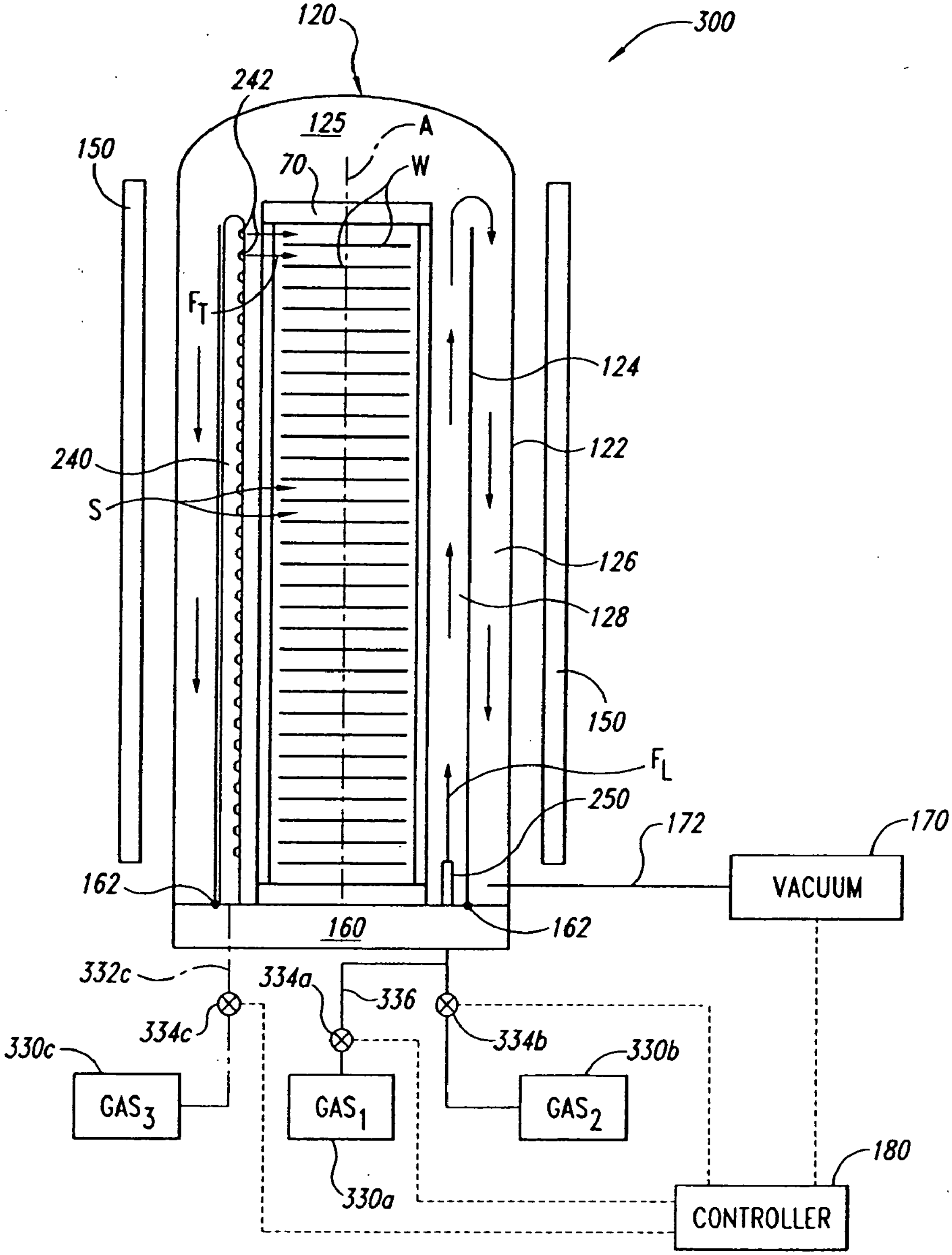

230a
GAS1
230b
GAS2
230c
GAS3
234a
234b
234c
236
200
120
172
170
VACUUM
250
126
128
240
70
7
FT
W
A
250
70
250
250
70
250
250
7
124
125
122

Fig. 8



300
120
242
125
A
150
70
W
FT
124
122
240
S
126
128
150
FL
250
172
170
VACUUM
162
160
162
332c
334a
336
334c
334b
330c
330b
GAS3
GAS1
GAS2
180
330a
CONTROLLER

Fig. 9

METHODS AND APPARATUS FOR PROCESSING MICROFEATURE WORKPIECES, E.G., FOR DEPOSITING MATERIALS ON MICROFEATURE WORKPIECES

TECHNICAL FIELD

[0001] The present invention is related to equipment and methods for processing microfeature workpieces, e.g., semiconductor wafers. Aspects of the invention have particular utility in connection with batch deposition of materials on microfeature workpieces, such as by atomic layer deposition or chemical vapor deposition.

BACKGROUND

[0002] Thin film deposition techniques are widely used in the manufacturing of microfeatures to form a coating on a workpiece that closely conforms to the surface topography. In the context of microelectronic components, for example, the size of the individual components in the devices on a wafer is constantly decreasing, and the number of layers in the devices is increasing. As a result, the density of components and the aspect ratios of depressions (e.g., the ratio of the depth to the size of the opening) are increasing. The size of such wafers is also increasing to provide more real estate for forming more dies (i.e., chips) on a single wafer. Many fabricators are currently transitioning from 200 mm to 300 mm workpieces, and even larger workpieces will likely be used in the future. Thin film deposition techniques accordingly strive to produce highly uniform conformal layers that cover the sidewalls, bottoms, and corners in deep depressions that have very small openings.

[0003] One widely used thin film deposition technique is chemical vapor deposition (CVD). In a CVD system, one or more precursors that are capable of reacting to form a solid thin film are mixed in a gas or vapor state, and then the precursor mixture is presented to the surface of the workpiece. The surface of the workpiece catalyzes the reaction between the precursors to form a solid thin film at the workpiece surface. A common way to catalyze the reaction at the surface of the workpiece is to heat the workpiece to a temperature that causes the reaction.

[0004] Although CVD techniques are useful in many applications, they also have several drawbacks. For example, if the precursors are not highly reactive, then a high workpiece temperature is needed to achieve a reasonable deposition rate. Such high temperatures are not typically desirable because heating the workpiece can be detrimental to the structures and other materials already formed on the workpiece. Implanted or doped materials, for example, can migrate within silicon workpieces at higher temperatures. On the other hand, if more reactive precursors are used so that the workpiece temperature can be lower, then reactions may occur prematurely in the gas phase before reaching the intended surface of the workpiece. This is undesirable because the film quality and uniformity may suffer, and also because it limits the types of precursors that can be used.

[0005] Atomic layer deposition (ALD) is another thin film deposition technique. **FIGS. 1A and 1B** schematically illustrate the basic operation of ALD processes. Referring to **FIG. 1A**, a layer of gas molecules A coats the surface of a workpiece W. The layer of A molecules is formed by exposing the workpiece W to a precursor gas containing A molecules, and then purging the chamber with a purge gas to remove excess A molecules. This process can form a monolayer of A molecules on the surface of the workpiece W because the A molecules at the surface are held in place during the purge cycle by physical adsorption forces at moderate temperatures or chemisorption forces at higher temperatures. The layer of A molecules is then exposed to another precursor gas containing B molecules. The A molecules react with the B molecules to form an extremely thin layer of solid material C on the workpiece W. The chamber is then purged again with a purge gas to remove excess B molecules.

[0006] **FIG. 2** illustrates the stages of one cycle for forming a thin solid layer using ALD techniques. A typical cycle includes (a) exposing the workpiece to the first precursor A, (b) purging excess A molecules, (c) exposing the workpiece to the second precursor B, and then (d) purging excess B molecules. The purge process typically comprises introducing a purge gas, which is substantially nonreactive with either precursor, and exhausting the purge gas and excess precursor from the reaction chamber in a pumping step. In actual processing, several cycles are repeated to build a thin film on a workpiece having the desired thickness. For example, each cycle may form a layer having a thickness of approximately 0.5-1.0 Å, and thus it takes approximately 60-120 cycles to form a solid layer having a thickness of approximately 60 Å.

[0007] One drawback of ALD processing is that it has a relatively low throughput compared to CVD techniques. For example, ALD processing typically takes several seconds to perform each A-purge-B-purge cycle. This results in a total process time of several minutes to form a single thin layer of only 60 Å. In contrast to ALD processing, CVD techniques only require about one minute to form a 60 Å thick layer. In single-wafer processing chambers, ALD processes can be 500%-2000% longer than corresponding single-wafer CVD processes. The low throughput of existing single-wafer ALD techniques limits the utility of the technology in its current state because the ALD process may be a bottleneck in the overall manufacturing process.

[0008] One promising solution to increase the throughput of ALD processing is processing a plurality of wafers (e.g., 20-250) simultaneously in a batch process. **FIG. 3** schematically illustrates a conventional batch ALD reactor **10** having a processing enclosure **20** coupled to a gas supply **30** and a vacuum **40**. The processing enclosure **20** generally includes an outer wall **22** and an annular liner **24**. A platform **60** seals against the outer wall **22** or some other part of the processing enclosure **20** via a seal **62** to define a process chamber **25**. Gas is introduced from the gas supply **30** to the process chamber **25** by a gas nozzle **32** that introduces gas into a main chamber **28** of the process chamber **25**. Under influence of the vacuum **40**, the gas introduced via the gas nozzle **32** will flow through the main chamber **28** and outwardly into an annular exhaust **26** to be drawn out with the vacuum **40**. A plurality of workpieces W, e.g., semiconductor wafers, may be held in the processing enclosure **20** in a workpiece holder **70**. In operation, a heater **50** heats the workpieces W to a desired temperature and the gas supply **30** delivers the first precursor A, the purge gas, and the second precursor B as discussed above in connection with **FIG. 2**.

[0009] However, when depositing material simultaneously on a large number of workpieces in an ALD reactor **10** such as that shown in **FIG. 3**, it can be difficult to uniformly deposit the precursors A and B across the surface of each of the workpieces W. Removing excess precursor from the spaces between the workpieces W can also be problematic. In an ALD reactor **10** such as that shown in **FIG. 3**, diffusion is the primary mechanism for removing residual precursor that is not chemisorbed on the surface of one of the workpieces. This is not only a relatively slow process that significantly reduces the throughput of the reactor **10**, but it also may not adequately remove residual precursor. As such, conventional batch ALD reactors may have a low throughput and form nonuniform films.

[0010] In U.S. Patent Application Publication 2003/0024477 (the entirety of which is incorporated herein by reference), Okuda et al. suggest a system that employs a large plenum extending along the interior wall of a reaction tube. This plenum has a series of slots along its length with the intention of flowing gas parallel to the surfaces of the substrates treated in the tube. Although Okuda et al. suggest that this system may be used in both CVD and ALD applications, using such a system in ALD systems can be problematic. If a second precursor is introduced into the plenum before the first precursor is adequately purged from the plenum, the two precursors may react within the plenum. As a consequence, sufficient purge gas must be delivered to the plenum to adequately clear the first precursor, which may require even longer purge processes between delivery of the precursors. Such extended purges will reduce throughput and increase manufacturing costs. Throughput may be maintained by selecting less reactive precursors, but such precursors may require higher workpiece temperatures or preclude the use of some otherwise desirable precursors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] **FIGS. 1A and 1B** are schematic cross-sectional views of stages in ALD processing in accordance with the prior art.

[0012] **FIG. 2** is a graph illustrating a cycle for forming a layer using ALD techniques in accordance with the prior art.

[0013] **FIG. 3** is a schematic representation of a system including a reactor for depositing a material onto a microfeature workpiece in accordance with the prior art.

[0014] **FIG. 4** is a schematic longitudinal cross-sectional view, taken along line **4-4** of **FIG. 5**, of a microfeature workpiece processing system in accordance with one embodiment of the invention.

[0015] **FIG. 5** is a schematic transverse cross-sectional view of the microfeature workpiece processing system of **FIG. 4**, taken along line **5-5** of **FIG. 4**.

[0016] **FIG. 6** is a schematic transverse cross-sectional view of a microfeature workpiece processing system in accordance with a modified embodiment of the invention.

[0017] **FIG. 7** is a schematic longitudinal cross-sectional view, taken along line **7-7** of **FIG. 8**, of a microfeature workpiece processing system in accordance with another embodiment of the invention.

[0018] **FIG. 8** is a schematic transverse cross-sectional view of the microfeature workpiece processing system of **FIG. 7**, taken along the line **8-8** in **FIG. 7**.

[0019] **FIG. 9** is a schematic longitudinal cross-sectional view of a microfeature workpiece processing system in accordance with still another embodiment of the invention.

DETAILED DESCRIPTION

A. Overview

[0020] Various embodiments of the present invention provide microfeature workpiece processing systems and methods for depositing materials onto microfeature workpieces. Many specific details of the invention are described below with reference to exemplary systems for depositing materials onto microfeature workpieces. The term "microfeature workpiece" is used throughout to include substrates upon which and/or in which microelectronic devices, micromechanical devices, data storage elements, read/write components, and other features are fabricated. For example, microfeature workpieces can be semiconductor wafers such as silicon or gallium arsenide wafers, glass substrates, insulative substrates, and many other types of materials. The microfeature workpieces typically have submicron features with dimensions of 0.05 microns or greater. Furthermore, the term "gas" is used throughout to include any form of matter that has no fixed shape and will conform in volume to the space available, which specifically includes vapors (i.e., a gas having a temperature less than the critical temperature so that it may be liquefied or solidified by compression at a constant temperature). Moreover, the term "transverse" is used throughout to mean oblique, perpendicular, and/or not parallel. Several embodiments in accordance with the invention are set forth in **FIGS. 4-9** and the following text to provide a thorough understanding of particular embodiments of the invention. A person skilled in the art will understand, however, that the invention may have additional embodiments, or that the invention may be practiced without several of the details of the embodiments shown in **FIGS. 4-9**.

[0021] Some embodiments of the invention provide microfeature workpiece processing systems. In one such embodiment, a microfeature workpiece processing system includes a process chamber, a first gas conduit, a second gas conduit, a first gas supply line, and a second gas supply line. The process chamber has a workpiece area adapted to receive a plurality of spaced-apart microfeature workpieces arranged relative to a longitudinal axis of the process chamber. The first gas conduit extends longitudinally within the process chamber proximate the workpiece area. This first gas conduit may have a plurality of first outlets spaced longitudinally along a length of the first gas conduit. The first outlets may be oriented toward the workpiece area and adapted to direct a first gas flow transverse to the longitudinal axis. In one embodiment, the second gas conduit may also extend longitudinally within the process chamber proximate the workpiece area and include a plurality of second outlets spaced longitudinally along a length of the second gas conduit. The second outlets may be oriented toward the workpiece area and adapted to direct the second gas flow transverse to the longitudinal axis. The direction of the second gas flow may be transverse to the direction of the first gas flow. The first gas supply line may be adapted to deliver a first gas to the first gas conduit, and the second gas supply line may be adapted to deliver a second gas to the second gas conduit. The second gas supply line may be independent of the first gas supply line, and the second gas may be different from the first gas.

[0022] A microfeature workpiece processing system in accordance with another embodiment of the invention includes a process chamber, a first gas conduit, a second gas conduit, a first gas supply line, and a second gas supply line. The process chamber may be adapted to receive a plurality of transversely oriented microfeature workpieces spaced from one another in a longitudinal direction. The first gas conduit may extend longitudinally within the process chamber and include a plurality of outlets spaced longitudinally along a length of the first gas conduit; each of the outlets is oriented to direct a first gas flow transversely across a surface of one of the workpieces. The second gas conduit may have a second outlet oriented to direct a second gas flow longitudinally within the process chamber, e.g., generally perpendicular to the direction of the first gas flow. The first gas supply line is adapted to deliver a first gas to the first gas conduit, and the second gas supply line is adapted to deliver a second gas to the second gas conduit.

[0023] An alternative embodiment of the invention provides a method of depositing a reaction product on each of a batch of microfeature workpieces. In accordance with this method, a plurality of workpieces may be positioned in the process chamber, with the workpieces spaced from one another in a first direction to define a process space between each pair of adjacent workpieces. A first gas may be delivered to an elongate first delivery conduit that has a length in the first direction and may direct a first gas flow of the first gas into at least one of the process faces from each of a plurality of outlets spaced in the first direction along the length of the first delivery conduit. Each of the first gas flows is directed to flow along a first vector transverse to the first direction. A second gas may be delivered to an elongate second delivery conduit that has a length in the first direction. A second gas flow of the second gas may be directed into at least one of the process spaces from each of a plurality of outlets spaced in the first direction along the length of the second delivery conduit. Each of the second gas flows may be directed to flow along a second vector that is transverse to the first direction and may also be transverse to the first vector.

[0024] An alternative embodiment of the invention provides a method of depositing a reaction product that includes positioning a plurality of microfeature workpieces similar to the previous method. A first gas may be delivered to a first delivery conduit and directed into process spaces between the workpieces as in the prior embodiment. In this embodiment, however, a second gas is delivered to a second delivery conduit and a second gas flow of the second gas is directed in the first direction, which may be substantially perpendicular to the first gas flow.

[0025] For ease of understanding, the following discussion is subdivided into two areas of emphasis. The first section discusses microfeature workpiece processing systems in accordance with selected embodiments of the invention. The second section outlines methods in accordance with other aspects of the invention.

B. Microfeature Workpiece Processing System

[0026] **FIGS. 4 and 5** schematically illustrate a microfeature workpiece processing system **100** in accordance with one embodiment of the invention. The processing system **100** includes a reactor **110** adapted to receive a plurality of microfeature workpieces W, which may be carried in a workpiece holder **70**. The reactor **110** generally includes an enclosure **120** defined by an outer wall **122** and a platform **160** (**FIG. 4**) upon which the workpiece holder **70** may be supported. The outer wall **122** may sealingly engage the platform **160** (schematically illustrated in **FIG. 4** as an O-ring seal **162**). This will define a process chamber **125** within which the workpiece holder **70** and microfeature workpieces W may be received. In the embodiment shown in **FIG. 4**, the workpieces W are positioned in a workpiece area of the process chamber **125** that is substantially centered about a longitudinal axis A of the process chamber **125**.

[0027] This particular reactor **110** includes an annular liner **124** that may functionally divide the process chamber **125** into a main chamber **128** and an annular exhaust **126**. The annular exhaust **126** may be in fluid communication with a vacuum **170**, e.g., a vacuum pump, via a vacuum line **172**. During the pumping phase of the purge process noted above in connection with **FIG. 2**, the vacuum **170** may exhaust gas from the main chamber **128** via this annular exhaust **126**.

[0028] The reactor **110** may also include a heater **150**. The heater **150** can be any conventional design. In one exemplary embodiment, the heater **150** may comprise an induction heater. Other suitable heaters **150** for use in connection with particular processes to be carried out in the processing system **100** will be readily apparent to those skilled in the art.

[0029] The processing system **100** also includes a first gas conduit **140***a* and a second gas conduit **140***b* that extend longitudinally within the main chamber **128** of the process chamber **125**. The gas conduits **140***a-b* are positioned proximate the workpiece area where the workpieces W are received. Each of the gas conduits **140** includes a plurality of outlets **142** spaced longitudinally along its length and oriented toward the workpieces W. In the illustrated embodiment, the outlets **142** of each of the gas conduits **140** are adapted to direct a flow of gas from one of the gas supplies **130***a-c* (discussed below) transverse to the longitudinal axis A of the process chamber **125**. In one specific implementation, the outlets **142** may be oriented to direct a flow of gas perpendicular to this axis A. The first and second gas conduits **140***a* and **140***b* may be positioned within the main chamber **128** of the enclosure **120** in any suitable relative orientation. In the illustrated embodiment, the gas conduits **140***a* and **140***b* are substantially parallel to one another and oriented at an angle less than 180 degrees from one another. If so desired, the outlets **142** of the first gas conduit **140***a* may be oriented to direct a flow of gas generally parallel to the direction in which the outlets **142** of the second gas conduit **140***b* direct the flow of gas from the second gas conduit **140***b*. In the illustrated embodiment, the outlets **142** of the first gas conduit **140***a* may direct a first gas flow along a flow vector F_1 (**FIG. 5**) oriented generally toward the longitudinal axis A of the chamber **125**, which may substantially coincide with the center of each workpiece W. The outlets **142** of the second gas conduit **140***b* may orient a second flow of gas along a second flow vector F_2 (**FIG. 5**) that is also oriented toward the longitudinal axis A. These two flow vectors F_1 and F_2 may be oriented transverse to one another. In CVD applications or in the purge processes of ALD, such transverse flow may facilitate high throughput without unduly compromising quality and uniformity.

[0030] The outlets **142** can also be positioned relative to the orientation of the workpieces W. The workpieces W are spaced apart in the workpiece holder **70** and oriented generally parallel to one another such that a process space S separates each pair of adjacent workpieces W. The outlets **142** can be configured to direct a flow of gas from respective gas conduit **140***a* or **140***b* transversely into each process space S. As a consequence, a flow of gas can be established transversely across a surface of each workpiece W. If the gas conduits **140***a* and **140***b* are used to deliver precursor gases in an ALD or CVD process, this transverse flow through the process spaces and across the surfaces of the workpieces W is expected to enhance the uniformity of material deposition on the surfaces of the workpieces W. If a purge gas is delivered through one or both of the gas conduits **140***a* and **140***b*, this transverse flow of gas along the flow vectors F_1 and/or F_2 can efficiently purge the process spaces S of any excess precursor gas.

[0031] The processing system **100** also includes at least two gas supplies. In particular, a first gas supply **130***a* of a first gas (GAS_1) is coupled to the first gas conduit **140***a* by a first gas supply line **132***a*. Similarly, a second gas supply **130***b* of a second gas (GAS_2) is coupled to the second gas conduit **140***b* by a second gas supply line **132***b*. If so desired, a first gas supply valve **134***a* may be provided in the first gas supply line **132***a* and a second gas supply valve **134***b* may be provided in the second gas supply line **132***b*. The processing system **100** may also include a third gas supply **130***c* adapted to provide a third gas (GAS_3), e.g., a purge gas, via a third gas supply line **132***c*. The third gas supply line **132***c* may be in fluid communication with the first gas supply line **132***a* and/or the second gas supply line **132***b*. This would permit delivery of the third gas (GAS_3) from the third gas supply line **130***c* to the process chamber **125** via one or both of the gas conduits **140***a* and **140***b*. A third gas supply valve **134***c* may be provided in the third gas supply line **132***c*.

[0032] The gas supply valves **134***a-c* may be operated to selectively introduce the desired process gas (e.g., GAS_1, GAS_2, GAS_3) under the direction of a controller **180**. In one embodiment, the controller **180** comprises a computer having a programmable processor programmed to control operation of the processing system **100** to deposit material on the workpieces W. The controller **180** may be coupled to the vacuum **170** to control its operation. The controller **180** may also be operatively connected to the heater **150** to control the temperature of the workpieces W and/or an actuator (not shown) to move the platform **160** toward or away from the outer wall **122**, as suggested by the arrow L, to allow the workpieces W to be loaded into or moved from the process chamber **125**.

[0033] The composition of the gases in the gas supplies **130***a-c* can be varied depending on the process to be carried out in the processing system **100**. If the processing system **100** is used in an ALD process, for example, the first gas supply **130***a* may contain a first precursor (e.g., precursor A discussed above in **FIGS. 1 and 2**) and the second gas supply **130***b* may contain a second precursor (e.g., precursor B in **FIGS. 1 and 2**). The reaction tube suggested by Okuda et al. in U.S. Patent Application Publication US 2003/0024477 delivers all the gases to a relatively large common plenum. As discussed above, this plenum arrangement can have a number of disadvantages, including longer purge times, decreased throughput, and increased manufacturing costs. In contrast, the microfeature workpiece processing system **100** of **FIGS. 4 and 5** may deliver the reaction precursors through separate gas conduits **140**. Using separate gas conduits **140** permits a transverse flow of gas through the process spaces S to enhance product uniformity and throughput, but avoids the problems expected to be encountered in a system that employs a single common plenum such as that suggested by Okuda et al.

[0034] **FIG. 6** schematically illustrates a microfeature workpiece processing system **102** in accordance with another embodiment of the invention. This processing system **102** may be similar in many respects to the processing system **100** of **FIGS. 4 and 5** and like reference numbers are used to indicate like elements in **FIGS. 4-6**. The processing system **100** of **FIGS. 4 and 5** includes a single first gas conduit **140***a* and a single second gas conduit **140***b*, each of which is adapted to deliver a separate gas, i.e., GAS_1 or GAS_2, respectively. The processing system **102** of **FIG. 6**, however, includes several first gas conduits **140***a* and several second gas conduits **140***b*. In the specific implementation shown in this figure, three first gas conduits **140***a* are spaced approximately equiangularly about the periphery of the workpiece area where the workpieces W are received. Each of the first gas conduits **140***a* is adapted to direct a flow of gas along a flow vector F_1 that is oriented toward and perpendicular to the longitudinal axis A of the process chamber (**125** in **FIG. 4**). As a consequence, each of the first gas flow vectors F_1 are transverse to one another, as well. The three second gas conduits **104***b* of **FIG. 6** also may be spaced approximately equiangularly about the periphery of the workpiece area. Each of the second gas conduits **140***b* is adapted to direct a second flow of gas along a second gas flow vector F_2 that is oriented toward and perpendicular to the longitudinal axis A of the process chamber **125** and transverse to one another. It is anticipated that the use of multiple flow vectors for each gas supply can further enhance uniformity of gas distribution across the surfaces of the workpieces W.

[0035] **FIGS. 7 and 8** illustrate a microfeature workpiece processing system **200** in accordance with another embodiment of the invention. Many of the elements of the processing system **200** may be substantially the same as elements of the processing system **100** of **FIGS. 4 and 5** and like reference numbers are used in both pairs of drawings to indicate like elements.

[0036] The microfeature workpiece processing system **200** of **FIGS. 7 and 8** includes a single longitudinally extending gas conduit **240** deposed within the main chamber **128** of the enclosure **120**. A number of outlets **242** may be spaced longitudinally along a length of the gas conduit **240**, with at least one outlet **242** associated with each process space S defined by the workpieces W. The construction and orientation of the gas conduit **240** may be substantially the same as that of the first or second gas conduit **140***a* or **140***b* of **FIGS. 4 and 5**. As a consequence, the outlets **242** of the gas conduit **240** are adapted to direct a flow of gas along a transverse flow vector F_T, which may be oriented generally toward the center of an associated process space S and generally perpendicular to the longitudinal axis A of the process chamber **125**.

[0037] The specific microfeature workpiece processing system **200** shown in **FIGS. 7 and 8** includes the single gas conduit **240**. It should be understood, though, that any number of gas conduits **240** may be employed. By analogy to the plurality of first gas conduits **140***a* in **FIG. 6**, for example, a series of gas conduits **240** having a common gas supply (discussed below) may be spaced about the periphery of the workpiece area.

[0038] In addition to the gas conduit **240**, the processing system **200** of **FIGS. 7 and 8** includes one or more longitudinal conduits or nozzles **250** adapted to direct a flow of gas along a longitudinally oriented flow vector F_L. This flow vector F_L may be substantially parallel to the longitudinal axis A of the process chamber **125** and generally perpendicular to the transverse flow vectors F_T from the outlets **242** of the gas conduit **240**. In one embodiment, a single longitudinal nozzle **250** is positioned in the main chamber **128** of the enclosure **120**. As best seen in **FIG. 8**, though, the illustrated embodiment utilizes a number of longitudinal nozzles **250** arranged peripherally about the workpiece area in which the workpieces W are received. The particular implementation shown in **FIG. 8** positions five longitudinal nozzles **250** substantially equiangularly about this periphery, but any suitable number of longitudinal nozzles **250** may be employed.

[0039] The microfeature workpiece processing system **200** of **FIGS. 7 and 8** includes a plurality of gas supplies **230***a*, **230***b*, and **230***c* coupled to a common gas supply manifold **236**. A separate gas supply valve **234***a*, **234***b*, or **234***c* may be associated with each of the gas supplies **230***a*, **230***b*, and **230***c*, respectively. These gas supply valves **234** may be operatively coupled to the controller **180** to control the flow of gas through the common gas supply manifold **236**. The common gas supply manifold **236** may deliver a gas from one or more of the gas supplies **230***a-c* to the longitudinally extending gas conduit(s) **240** and the longitudinal nozzle(s) **250**. When the controller **180** opens one or more of the gas supply valves **234***a-c*, a gas can be delivered through the common gas supply manifold **236** simultaneously to the gas conduit **240** and each of the longitudinal nozzles **250**. This can enhance the bulk flow rate of the desired gas into the main chamber **128** of the enclosure **120** while establishing sufficient transverse flow of the gas through the process spaces S to achieve the necessary uniformity of gas distribution across the surfaces of the workpieces W or an appropriately swift purging of the process spaces S.

[0040] **FIG. 9** schematically illustrates a microfeature workpiece processing system **300** in accordance with yet another embodiment of the invention. Many of the elements of this processing system **300** may be substantially the same as the elements of the processing system **200** shown in **FIG. 7**; like reference numbers are used in **FIGS. 7 and 9** to indicate like elements.

[0041] One difference between the processing systems **200** and **300** of **FIGS. 7 and 9** relates to the gas supply. In the embodiment shown in **FIG. 7**, the gas conduit **240** and the longitudinal nozzles **250** share a common gas supply manifold **236**. In the embodiment shown in **FIG. 9**, the longitudinal nozzle(s) **250** is in fluid communication with a gas supply manifold **336**. This gas supply manifold **336** is coupled to a first gas supply **330***a* by a first gas supply valve **334***a* and a second gas supply **330***b* by a second gas supply valve **334***b*. The gas supply valves **334***a* and **334***b* are operatively connected to the controller **180** to control the composition and flow rate of gas delivered to the longitudinal nozzle(s) **250**.

[0042] The longitudinally extending gas conduit **240** is connected to an independent gas supply **330***c* via a third gas supply line **332***c*. A third gas supply valve **334***c* may be operatively connected to the controller **180** to control the flow of the third gas (GAS_3) delivered to the gas conduit **240**.

[0043] The composition of the gasses (GAS_1, GAS_2, and GAS_3) can be varied to achieve different process objectives. In one embodiment, the first gas supply **330***a* contains a first precursor A, the second gas supply **330***b* contains a second precursor B, and the third gas supply **330***c* includes a purge gas. This enables the precursors A and B to be delivered to the main chamber **128** of the enclosure **120** in a relatively conventional fashion. Delivering the purge gas (GAS_3) transversely through the outlets **242** can fairly rapidly purge any excess precursor in the process spaces S between the workpieces W. In contrast with the conventional ALD reactor **10** shown in **FIG. 3**, which relies primarily on diffusion to purge excess precursor from the process spaces S, the transverse flow of purge gas through the process spaces S can significantly reduce the time needed to conduct the purge cycle without adversely affecting quality of the deposited material.

C. Methods of Depositing Materials on Microfeature Workpieces

[0044] As noted above, other embodiments of the invention provide methods of processing microfeature workpieces. In the following discussion, reference is made to the particular microfeature workpiece processing system **100** shown in **FIGS. 4 and 5**. It should be understood, though, that reference to this particular processing system is solely for purposes of illustration and that the methods outlined below are not limited to any particular processing system shown in the drawings or discussed in detail above. In addition, the following discussion focuses primarily on ALD. It should be recognized, however, that the processes outlined below are not limited to ALD and may have utility in CVD applications and in connection with processes other than material deposition.

[0045] One embodiment of the invention provides a method of depositing a reaction product on each of a batch of microfeature workpieces. A plurality of microfeature workpieces W may be positioned in a workplace area of the process chamber **125**. In one embodiment, the workpieces W are held by a workpiece holder **70** in a spaced-apart relationship. In the embodiments illustrated above, the workpiece holder **70** orients the workpieces W generally perpendicular to the longitudinal axis A of the process chamber **125**, defining a series of transversely oriented process spaces S between the workpieces W.

[0046] A first gas may be delivered to the process chamber **125**. Using the processing system **100** of **FIG. 4** as an example, the first gas (GAS_1) may be delivered from the first gas supply **130***a* to the first gas conduit **140***a* by the first gas supply line **132***a*. This may be accomplished by the controller **180** sending a signal to open the first gas supply valve **134***a*. The first gas (GAS_1) is delivered transversely into the processing spaces S along a series of generally parallel first transverse flow vectors F_1. This first gas (GAS_1) may comprise a first precursor for the ALD reaction. Once a sufficient quantity of this precursor is delivered to the process spaces S to chemisorb a layer of the precursor on the surface of the workpiece W, the first gas supply valve **134***a* may be closed by the controller **180**. Thereafter, a purge gas (GAS_3) can be delivered through the first gas conduit **140***a* and/or the second gas conduit **140***b*. This transverse flow of purge gas through the process spaces S will fairly rapidly remove any excess precursor from the process spaces S. Either during the delivery of the purge gas or after the flow of the purge gas is terminated by closing the third gas supply valve **134***c*, the vacuum **170** may be actuated to exhaust gas from the process chamber **125** via the annular exhaust **126**. The vacuum **170** can continue to operate after the third gas supply valve **134***c* is closed by the controller **180** until a desired reduced pressure is achieved.

[0047] The controller **180** may open the second gas supply valve **134***b* to deliver a second precursor gas (GAS_2) from the second gas supply **130***b* via the second gas conduit **140***b*. The outlets **142** of the second gas conduit **140***b* will deliver a transverse flow of this second precursor to the process spaces S, facilitating reaction with the previously chemisorbed first precursor to yield the desired reaction product. After a sufficient quantity of the second precursor gas (GAS_2) is delivered to the process chamber **125**, the process chamber **125** may again be purged by delivering the purge gas (GAS_3) and pumping down the process chamber **125** using the vacuum **170**. This process can be repeated as many times as necessary to achieve a layer of material on the surfaces of the workpieces W having the desired thickness.

[0048] Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise,""comprising," and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense, that is to say, in a sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number, respectively. When the claims use the word "or" in reference to a list of two or more items, that word covers all of the following interpretations of the word any of the items in the list, all of the items in the list, and any combination of the items in the list.

[0049] The above-detailed descriptions of embodiments of the invention are not intended to be exhaustive or to limit the invention to the precise form disclosed above. While specific embodiments of, and examples for, the invention are described above for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. For example, whereas steps are presented in a given order, alternative embodiments may perform steps in a different order. The various embodiments described herein can be combined to provide further embodiments.

[0050] In general, the terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification, unless the above-detailed description explicitly defines such terms. While certain aspects of the invention are presented below in certain claim forms, the inventors contemplate the various aspects of the invention in any number of claim forms. Accordingly, the inventors reserve the right to add additional claims after filing the application to pursue such additional claim forms for other aspects of the invention.

1-29. (canceled)

30. A method of depositing a reaction product on each of a batch of microfeature workpieces, comprising:

positioning a plurality of microfeature workpieces in a process chamber, the microfeature workpieces being spaced from one another in a first direction to define a process space between pairs of adjacent workpieces;

delivering a first gas to an elongate first delivery conduit that has a length in the first direction and directing a first gas flow of the first gas into at least one of the process spaces from a plurality of outlets spaced in the first direction along the length of the first delivery conduit, the individual first gas flows being directed to flow along a first vector transverse to the first direction; and

after terminating the first gas flow, delivering a second gas to an elongate second delivery conduit that has a length in the first direction and directing a second gas flow of the second gas into at least one of the process spaces from a plurality of outlets spaced in the first direction along the length of the second delivery conduit, the individual second gas flows being directed to flow along a second vector transverse to the first direction.

31. The method of claim 30 wherein the first vectors are transverse to the second vectors.

32. The method of claim 30 wherein the first vectors are substantially parallel to one another.

33. The method of claim 30 wherein the second vectors are substantially parallel to one another.

34. The method of claim 30 wherein each of the first vectors and the second vectors are directed inwardly toward a center of one of the microfeature workpieces.

35. The method of claim 30 wherein the first gas comprises a first reaction precursor and the second gas comprises a purge gas that is different from the first reaction precursor.

36. The method of claim 30 wherein the first gas comprises a first reaction precursor and the second gas comprises a second reaction precursor that is adapted to react with the first reaction precursor to form the reaction product.

37. (canceled)

38. The method of claim 30 further comprising:

terminating the first gas flow;

exhausting the first gas from the process chamber; and, thereafter,

initiating the second gas flow.

39. The method of claim 30 further comprising:

terminating the first gas flow;

delivering a purge gas to the process chamber and exhausting the purge gas from the process chamber; and, thereafter,

initiating the second gas flow.

40. The method of claim 30 further comprising directing a third gas flow of the first gas along a third vector that extends in the first direction.

41. The method of claim 30 further comprising delivering a third gas flow of the first gas to the process chamber while directing the first gas flows, the third gas flow being directed to flow along a third vector that extends in the first direction and is transverse to the first gas flow.

42. The method of claim 41 further comprising delivering a fourth gas flow of the second gas to the process chamber while directing the second gas flows, the fourth gas flow being directed to flow along a fourth vector that extends in the first direction and is transverse to the second gas flow.

43. A method of depositing a reaction product on each of a batch of microfeature workpieces, comprising:

positioning a plurality of microfeature workpieces in a process chamber, the microfeature workpieces being spaced from one another in a first direction to define a process space between pairs of adjacent workpieces;

delivering a first gas to an elongate first delivery conduit that has a length in the first direction and directing a first gas flow of the first gas into at least one of the process spaces from a plurality of first outlets that are spaced in the first direction along the length of the first delivery conduit, the individual first gas flows being directed transverse to the first direction; and

delivering a second gas to a second delivery conduit and directing a second gas flow of the second gas from a second outlet in the first direction with the second outlet positioned at the process chamber.

44. The method of claim 43 wherein the first gas comprises a first reaction precursor and the second gas comprises a purge gas that is different from the first reaction precursor.

45. The method of claim 43 wherein the first gas comprises a first reaction precursor and the second gas comprises a second reaction precursor that is configured to react with the first reaction precursor to form the reaction product.

46. The method of claim 43, further comprising terminating the first gas flow before initiating the second gas flow.

47. The method of claim 43, further comprising:

terminating the first gas flow;

exhausting the first gas from the process chamber; and, thereafter,

initiating the second gas flow.

48. The method of claim 43, further comprising:

terminating the first gas flow;

delivering a purge gas to the process chamber and exhausting the purge gas from the process chamber; and, thereafter,

initiating the second gas flow.

49. The method of claim 43 wherein directing the first gas flow occurs while directing the second gas flow.

50. The method of claim 43, further comprising delivering a third gas to an elongate second delivery conduit that has a length in the first direction and directing a third gas flow of the third gas into at least one of the process spaces from a plurality of outlets spaced in the first direction along the length of the second delivery conduit, the individual third gas flows being directed to flow along a second vector transverse to the first direction.

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