US 20050087134A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2005/0087134 A1

Ahn (43) Pub. Date: Apr. 28, 2005

(54) METHODS, SYSTEMS, AND APPARATUS FOR UNIFORM CHEMICAL-VAPOR DEPOSITIONS

(75) Inventor: **Kie Y. Ahn**, Chappaqua, NY (US)

Correspondence Address:
SCHWEGMAN, LUNDBERG, WOESSNER & KLUTH, P.A.
P.O. BOX 2938
MINNEAPOLIS, MN 55402 (US)

(73) Assignee: **Micron Technology, Inc.**

(21) Appl. No.: **10/931,845**

(22) Filed: **Aug. 31, 2004**

Related U.S. Application Data

(62) Division of application No. 09/797,324, filed on Mar. 1, 2001, now Pat. No. 6,852,167.

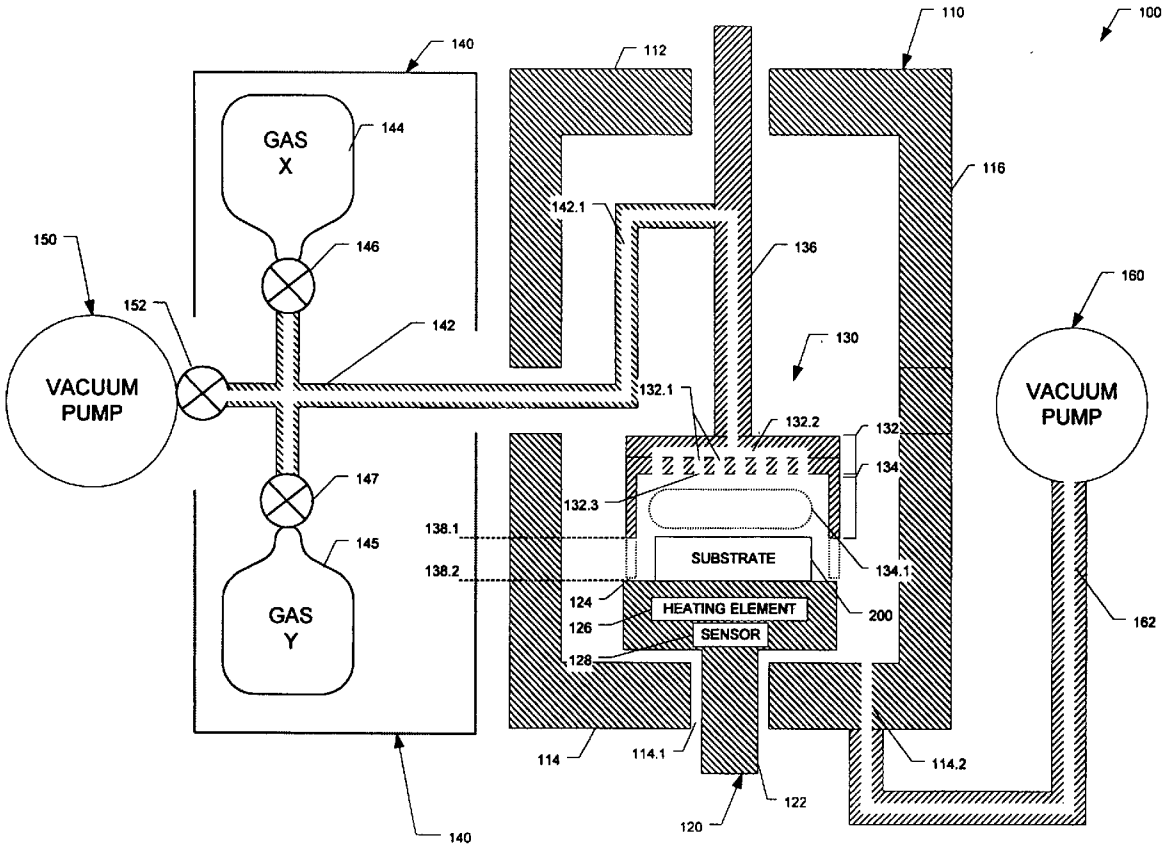
Publication Classification

(51) **Int. Cl.**[7] **C23C 16/00**

(52) **U.S. Cl.** **118/715**

(57) **ABSTRACT**

Integrated circuits, the key components in thousands of electronic and computer products, are generally built layer by layer on a silicon substrate. One common technique for forming layers is called chemical-vapor deposition (CVD.) Conventional CVD systems not only form layers that have non-uniform thickness, but also have large chambers that make the CVD process wasteful and slow. Accordingly, the inventor devised new CVD systems, methods, and apparatuses. One exemplary CVD system includes an outer chamber, a substrate holder, and a unique gas-distribution fixture. The fixture includes a gas-distribution surface having holes for dispensing a gas and a gas-confinement member that engages or cooperates with the substrate holder to form an inner chamber within the outer chamber. The inner chamber has a smaller volume than the outer chamber, which not only facilitates depositions of more uniform thickness, but also saves gas and speeds up the deposition process.



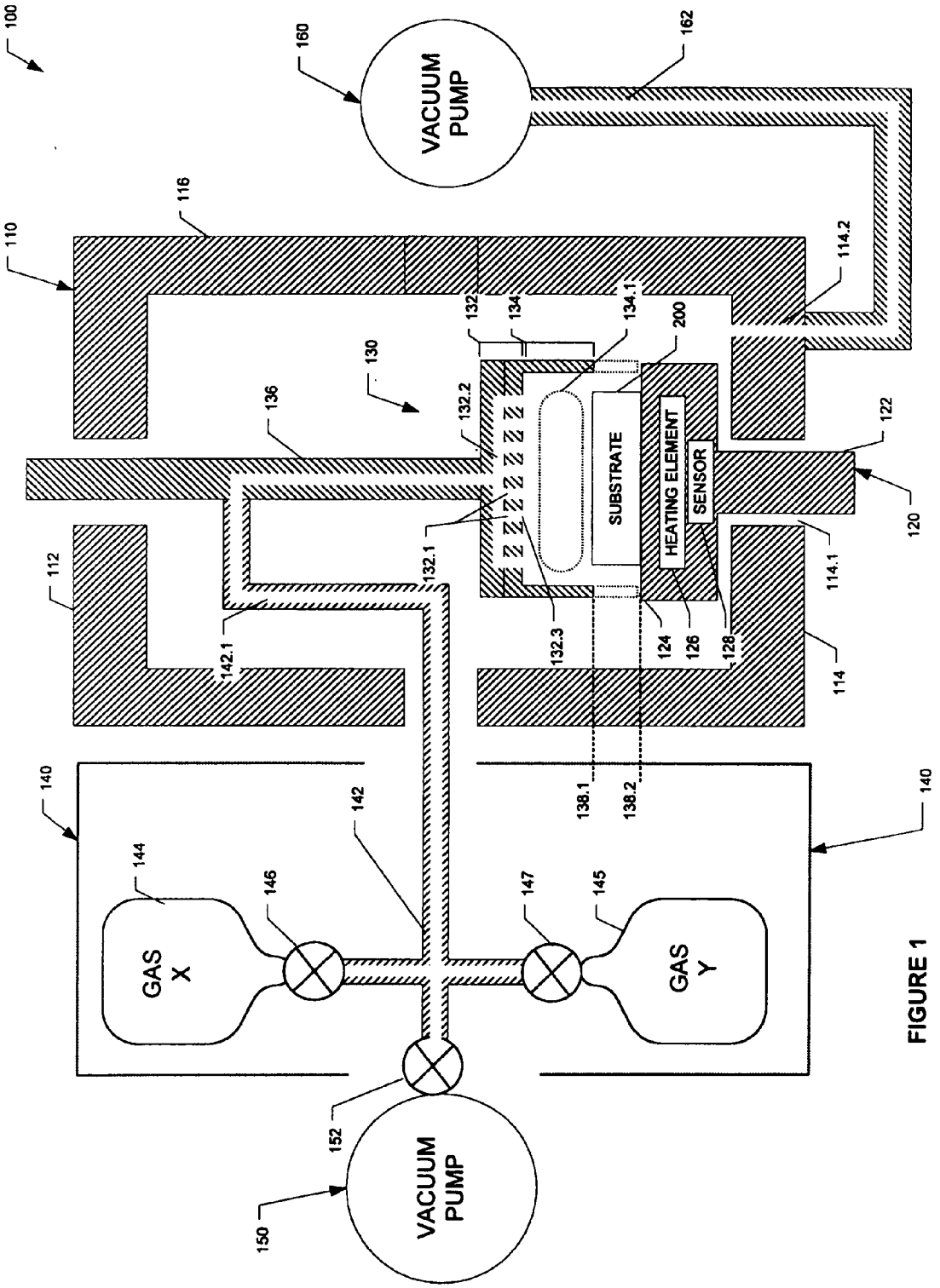

100
160
VACUUM PUMP
162
116
110
114.2
132
134
134.1
200
130
136
132.2
SUBSTRATE
HEATING ELEMENT
SENSOR
122
120
112
132.1
114.1
142.1
132.3
124
126
128
114
140
138.1
138.2
140
142
144
146
147
145
GAS X
GAS Y
152
150
VACUUM PUMP

FIGURE 1

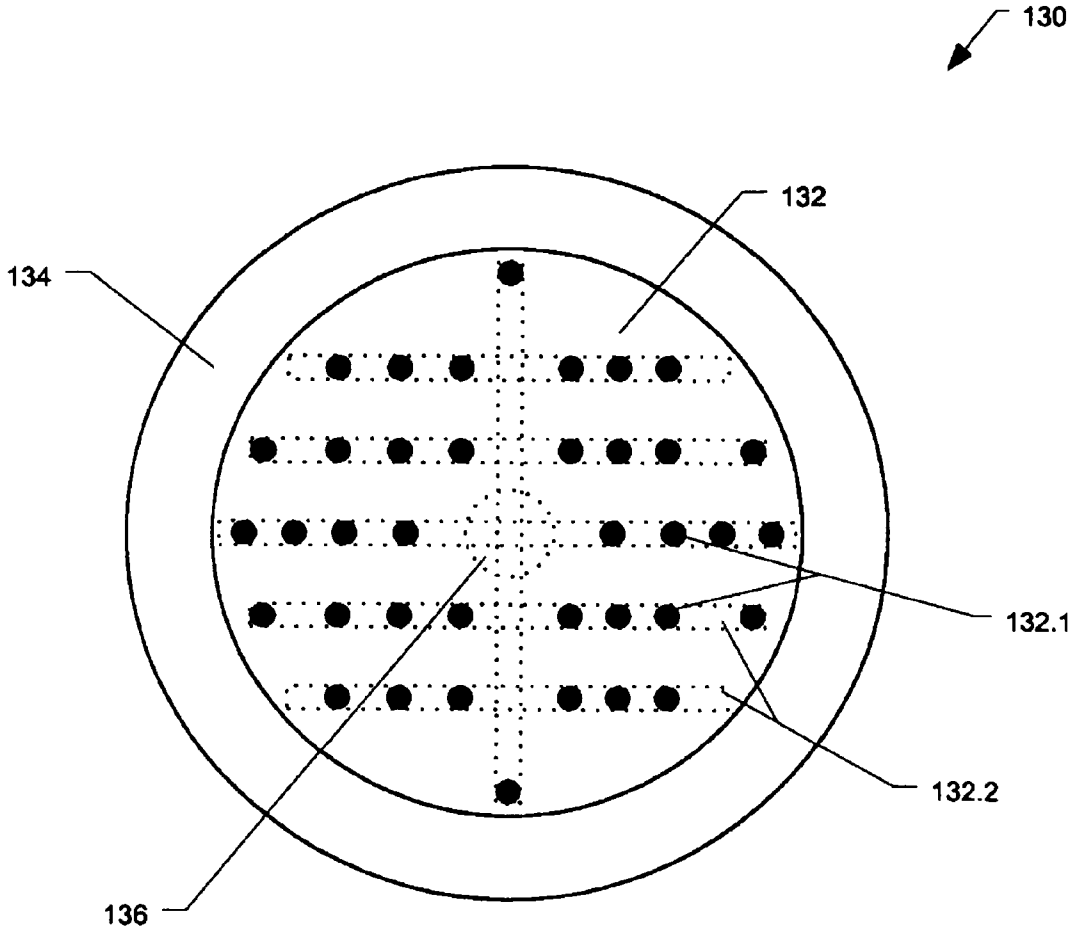


FIGURE 2

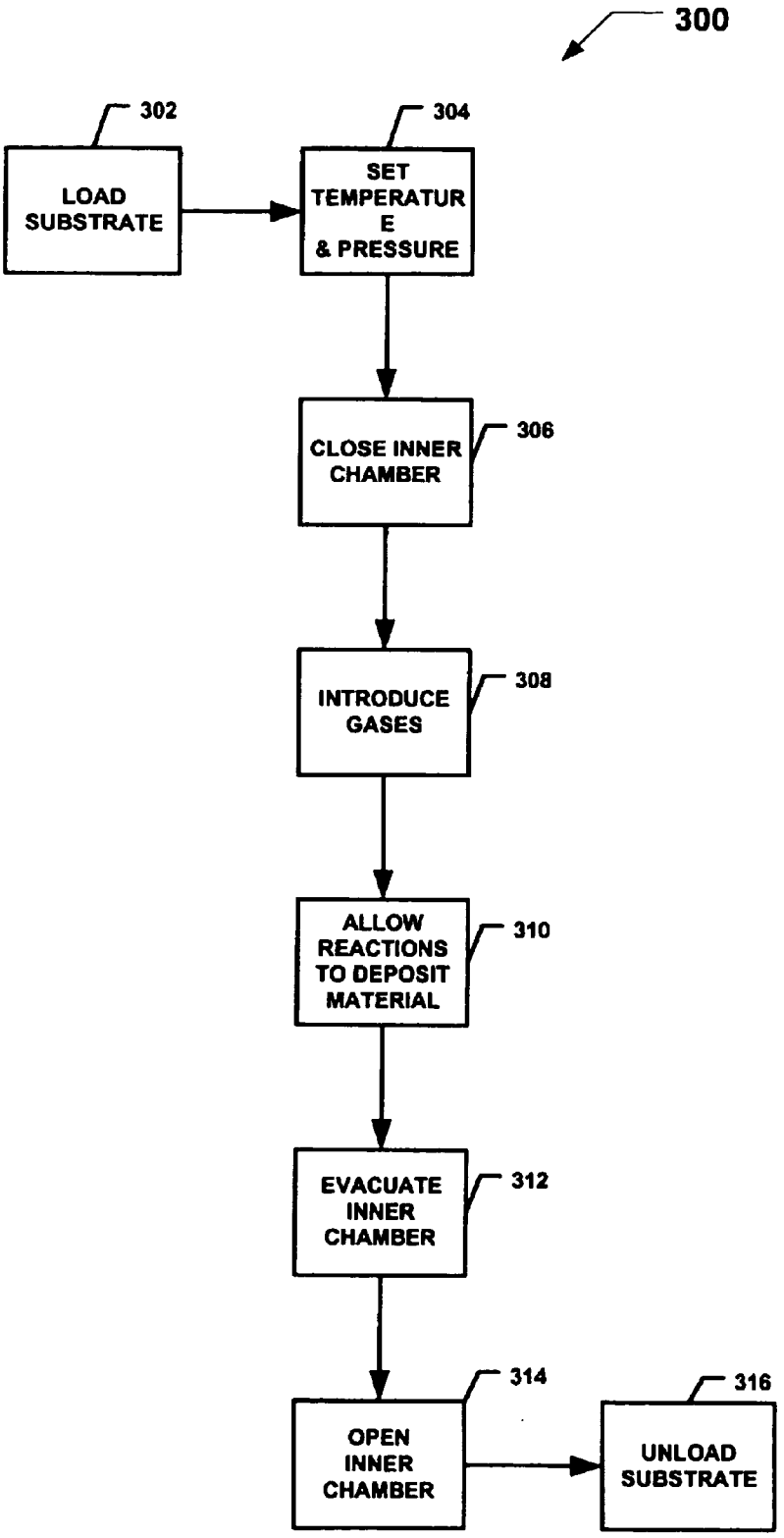

300
302
LOAD SUBSTRATE
304
SET TEMPERATURE & PRESSURE
CLOSE INNER CHAMBER
306
INTRODUCE GASES
308
ALLOW REACTIONS TO DEPOSIT MATERIAL
310
EVACUATE INNER CHAMBER
312
OPEN INNER CHAMBER
314
UNLOAD SUBSTRATE
316

FIGURE 3

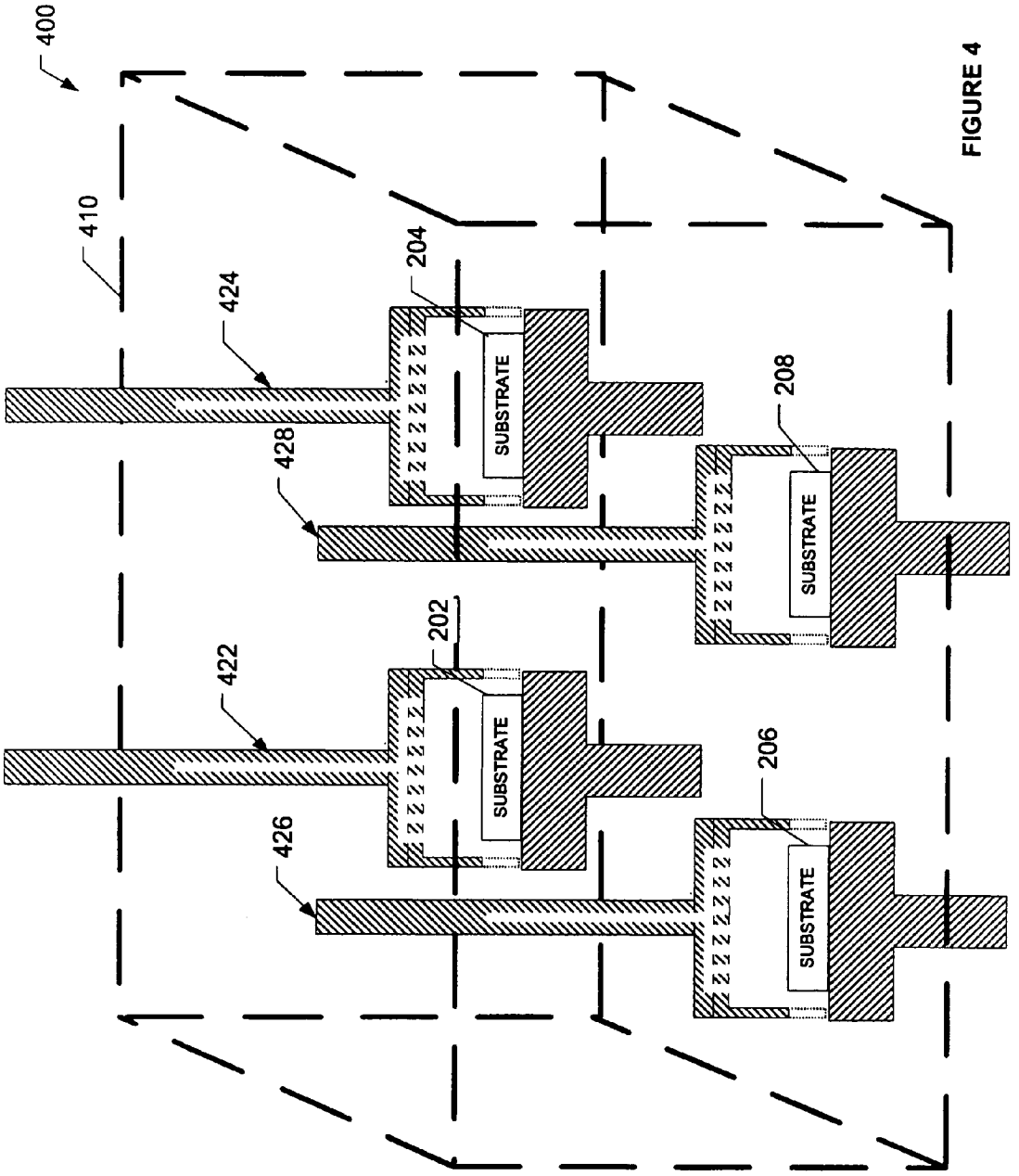

400
410
424
204
208
428
202
422
206
426
SUBSTRATE
SUBSTRATE
SUBSTRATE
SUBSTRATE

FIGURE 4

METHODS, SYSTEMS, AND APPARATUS FOR UNIFORM CHEMICAL-VAPOR DEPOSITIONS

[0001] This application is a Divisional of U.S. application Ser. No. 09/797,324, filed Mar. 1, 2001 which is incorporated herein by reference.

TECHNICAL FIELD

[0002] This invention concerns methods of making integrated circuits, particularly layer-formation, such as chemical-vapor deposition.

BACKGROUND OF THE INVENTION

[0003] Integrated circuits, the key components in thousands of electronic and computer products, are interconnected networks of electrical components fabricated on a common foundation, or substrate. Fabricators generally build these circuits layer by layer, using techniques, such as deposition, doping, masking, and etching, to form thousands and even millions of microscopic resistors, transistors, and other electrical components on a silicon substrate, known as a wafer. The components are then wired, or interconnected, together to define a specific electric circuit, such as a computer memory.

[0004] One common technique for forming layers in an integrated circuit is called chemical vapor deposition. Chemical vapor deposition generally entails placing a substrate in a reaction chamber, heating the substrate to prescribed temperatures, and introducing one or more gases, known as precursor gases, into the chamber to begin a deposition cycle. The precursor gases enter the chamber through a gas-distribution fixture, such as a gas ring or a showerhead, one or more centimeters above the substrate, and descend toward the heated substrate. The gases react with each other and/or the heated substrate, blanketing its surface with a layer of material. An exhaust system then pumps gaseous by-products or leftovers from the reaction out of the chamber through a separate outlet to complete the deposition cycle.

[0005] Conventional chemical-vapor-deposition (CVD) systems suffer from at least two problems. First, conventional CVD systems generally form layers that include microscopic hills and valleys and thus have non-uniform thickness. In the past, fabricators have been able to overcome these hills and valleys through use of post-deposition planarization or other compensation techniques. However, escalating demands for greater circuit density, for thinner layers, and for larger substrates make it increasingly difficult, if not completely impractical, to overcome the non-uniform thickness of conventional CVD layers.

[0006] Second, some conventional CVD systems are also inefficient and time consuming. One significant factor affecting both CVD efficiency and duration is the size of conventional reaction chambers, which are generally made large to allow a loading mechanism to insert and extract the substrate. Large chambers generally require more gases to be introduced to achieve desired gas concentrations. However, much of this gas is not only unnecessary based on the amount of material deposited, but is typically treated as waste. Moreover, large chambers also take longer to fill up or pump out, prolonging deposition cycles and thus slowing fabrication of integrated circuits.

[0007] Accordingly, there is a need for better systems and methods of chemical-vapor deposition.

SUMMARY OF THE INVENTION

[0008] To address these and other problems, the present inventor devised new systems, methods, and apparatuses for chemical-vapor deposition. One exemplary chemical-vapor deposition system includes an outer chamber, a substrate holder, and a unique gas-distribution fixture. The fixture includes a gas-distribution surface having holes for dispensing a gas and a gas-confinement member that forms a wall around the holes. In operation, the gas-confinement member engages, or otherwise cooperates with the substrate holder to form an inner chamber within the outer chamber.

[0009] The inner chamber has a smaller volume than the outer chamber and thus consumes less gas during the deposition process than would the outer chamber used alone. Also, the smaller chamber volume allows the exhaust system to pump the chamber more quickly, thus increasing the rate of the CVD process. In addition, the exemplary showerhead is made of a material, like silicon, which can be easily passivated to reduce reaction with reactive gases, thus reducing chemical-vapor buildup in the showerhead. Also, the exemplary showerhead includes a configuration of holes that permits uniform gas flow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] **FIG. 1** is a side view of an exemplary deposition reactor according to the invention;

[0011] **FIG. 2** is a top view of an exemplary gas-distribution fixture according to the invention;

[0012] **FIG. 3** is a flowchart showing an exemplary method according to the invention; and

[0013] **FIG. 4** is a diagram of an exemplary deposition system **400** incorporating a set of four deposition stations similar in structure and function to system **100** of **FIG. 1**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] The following detailed description, which references and incorporates **FIGS. 1-4**, describes and illustrates specific embodiments of the invention. These embodiments, offered not to limit but only to exemplify and teach the invention, are shown and described in sufficient detail to enable those skilled in the art to make and use the invention. Thus, where appropriate to avoid obscuring the invention, the description may omit certain information known to those of skill in the art.

[0015] **FIG. 1** shows an exemplary chemical-vapor-deposition system **100** which incorporates teachings of the present invention. In particular, system **100** includes a chamber **110**, a wafer holder **120**, a gas-distribution fixture **130**, a gas supply system **140**, and exhaust pump **150**, and a exhaust pump **160**.

[0016] More particularly, chamber **110** includes respective top and bottom plates **112** and **114** and a sidewall **116**. In the exemplary embodiment, chamber **110** is a cylindrical structure formed of stainless steel or glass. However, other embodiments use different structures and materials. Bottom

plate **114** includes an opening **114.1**. Extending through opening **114.1** is a stem portion **122** of wafer holder **120**.

[**0017**] Wafer holder **120** also includes a support platform **124**, one or more heating elements **126**, and one or more temperature sensors **128**. Support platform **124** supports one or more substrates, wafers, or integrated-circuit assemblies **200**. Substrate **200** has an exemplary width or diameter of about 30 centimeters and an exemplary thickness in the range of 850-1000 microns. (The term "substrate," as used herein, encompasses a semiconductor wafer as well as structures having one or more insulative, conductive, or semiconductive layers and materials. Thus, for example, the term embraces silicon-on-insulator, silicon-on-sapphire, and other advanced structures.) Heating elements **126** and temperature sensors **128** are used for heating substrates **200** to a desired temperature. Holder **120** is coupled to a power supply and temperature control circuitry (both of which are not shown.) In the exemplary embodiment, wafer holder **120** is rotatable either manually or automatically and raises via manual or automatic lever mechanism (not shown). Above wafer holder **120** and substrate **200** is gas-distribution fixture **130**.

[**0018**] Fixture **130** includes a gas-distribution member **132**, a surface-projection (or gas-confinement) member **134**, and a gas inlet **136**. Gas inlet **132** couples to gas-supply, gas-distribution channels **134**, and a gas inlet **136**. In the exemplary embodiment, fixture **130** has two operating positions **138.1** and **138.2** relative support platform **124**. Fixture **130** takes operating position **138.1**, before and after depositions and operating position **138.2** during depositions.

[**0019**] Gas-distribution member **132** includes gas-distribution holes, or orifices, **132.1** and gas-distribution channels **132.2**. Holes **132.1** define a gas-distribution surface **132.3**. In the exemplary embodiment, holes **132.1** are substantially circular with a common diameter in the range of 15-20 microns; gas-distribution channels **132.2** have a common width in the range of 20-45 microns; and surface **132.3** is substantially planar and parallel to support platform **124** of wafer holder **120**. However, other embodiments use other surface forms as well as shapes and sizes of holes and channels. The distribution and size of holes may also affect deposition thickness and thus might be used to assist thickness control. Holes **132.1** are coupled through gas-distribution channels **132.2** to gas inlet **136**.

[**0020**] Surface-projection member **134** projects or extends from surface **132.3** toward support platform **124**, defining a fixture cavity **134.1**. The exemplary embodiment forms surface-projection member **134** from stainless steel as a uniform annular or circular wall or collar that projects perpendicularly from surface **132** to define a right-cylindrical cavity. However, other embodiments form member **134** to project at other angles relative surface **132.3**. For example, some form the projection at an acute or obtuse angle, such as 45 or 135 degrees, and others form the projection to peripherally define an oval, ellipse, triangle, square, or any desirable regular or irregular polygon. Thus, the present invention encompasses a wide variety of projection shapes and configurations, indeed any projection shape that facilitates definition of an effective cavity or gas-confinement volume in cooperation with wafer holder **120** and/or substrate **200**.

[**0021**] **FIG. 2**, a plan view, shows further details of the exemplary embodiment of gas-distribution fixture **130**. In particular, the plan view shows not only exemplary circular peripheries of gas-distribution member **132** and surface-projection member **134**, but also an exemplary distribution pattern for holes **132.1** and an exemplary orthogonal arrangement of gas-distribution channels **132.2**. Other embodiments, however, use other hole distribution patterns and channel arrangements. For example, some embodiments include random or concentric hole patterns and various channel geometries, including concentric circles, rectangles, or other regular or irregular concentric polygons. Some embodiments may also dedicate various subsets of channels and corresponding holes to different gases.

[**0022**] Gas-distribution member **132** can be made in a number of ways. One exemplary method entails providing two wafers of materials, such as silicon or other passivatable, inert, or non-reactive material. One wafer is patterned and etched, for example, using conventional photolithographic or micro-electro-mechanical systems (MEMS) technology, to form a pattern holes, and the other wafer is patterned and etched to include a complementary or corresponding pattern of gas-distribution channels. (MEMS refers to the technologies of making structures and devices with micrometer dimensions.) Dry-etching techniques produce small openings and channels, while wet etching produces larger openings and channels. For further details, see, for example, M. Engelhardt, "Modern Application of Plasma Etching and Patterning in Silicon Process Technology," Contrib. Plasma Physics, vol. 39, no. 5, pp. 473-478 (1999).

[**0023**] The two wafers are then bonded together with the holes and channels in appropriate alignment using known wafer-bonding techniques. See, for example, G. Krauter et al., "Room Temperature Silicon Wafer Bonding with Ultra-Thin Polymer Films," Advanced Materials, vol. 9, no. 5, pp. 417-420 (1997); C. E. Hunt et al., "Direct Bonding of Micromachined Silicon Wafers for Laser Diode Heat Exchanger Applications," J. Micromech. Microeng, vol. 1, pp. 152-156 (1991); Zucker, O. et al., "Applications of oxygen plasma processing to silicon direct bonding," Sensors and Actuators, A. Physical, vol. 36, no. 3, pp. 227-231 (1993), which are all incorporated herein by reference. See also, copending and co-assigned U.S. patent application Ser. No. 09/189,276 (dockets 303.534US1 and 97-1468) entitled "Low Temperature Silicon Wafer Bond Process with Bulk Material Bond Strength," which was filed Nov. 10, 1998 and which is also incorporated herein by reference. The resulting bonded structure is then passivated using thermal oxidation for example.

[**0024**] For an alternative fixture structure and manufacturing method that can be combined with those of the exemplary embodiment, see U.S. Pat. No. 5,595,606, entitled "Shower Head and Film Forming Apparatus Using Same, which is incorporated herein by reference. In particular, one embodiment based on this patent adds a projection or gas-confinement member to the reported showerhead structure.

[**0025**] **FIG. 1** also shows that gas inlet **136** couples gas-distribution fixture **130** to gas-supply system **140**. Gas-supply system **140** includes a gas line **142**, gas sources **144** and **145**, and mass-flow controllers **146** and **147**. Gas line or conduit **142**, which includes a flexible portion **142.1**, passes through an opening **116.1** in chamber sidewall **116** to connect with gas inlet **136**. Gas source **144** is coupled via

mass-flow controller **146** to gas line **142**, and gas source **147** is coupled via mass-flow controller **147** to gas line **142**. The exemplary embodiment provides computer-controlled thermal or pressure-based mass-flow controllers; however, the invention is not limited to any particular number or type of mass-flow controller, nor to any particular number or set of gas sources.

[**0026**] System **100** also includes vacuum pumps **150** and **160**. Vacuum pump **150** is coupled to gas-distribution fixture **130** via a mass-flow controller **152** and gas line **142**. And, vacuum pump **160** is coupled to the interior of chamber **110** via a line **162** and an opening **114.2** in chamber bottom plate **114**. In the exemplary embodiment, vacuum pump **160** has a greater capacity than vacuum pump **150**.

[**0027**] In general operation, system **100** functions, via manual or automatic control, to move gas-distribution fixture **130** from operating position **138.1** to position **138.2**, to introduce reactant gases through fixture **130** onto substrate **200**, and to deposit desired matter through chemical-vapor deposition onto the substrate. After the desired matter is deposited, pump **150** evacuates gases through fixture **130**.

[**0028**] More particularly, **FIG. 3** shows a flowchart **300** which illustrates an exemplary method of operating system **100**. Flowchart **300** includes process blocks **202-216**.

[**0029**] The exemplary method begins at block **302** with insertion of substrate **300** onto wafer holder **120**. Execution then proceeds to block **304**.

[**0030**] Block **304** establishes desired temperature and pressure conditions within chamber **110**. In the exemplary embodiment, this entails operating heating element **126** to heat substrate **200** to a desired temperature, and operating vacuum pump **160** to establish a desired pressure. Temperature and pressure are selected based on a number of factors, including composition of the substrate and reactant gases, as well as the desired reaction. After establishing these deposition conditions, execution continues at block **306**.

[**0031**] In block **306**, the system forms or closes an inner chamber around substrate **200**, or more precisely a portion of substrate **200** targeted for deposition. In the exemplary embodiment, this entails using a lever or other actuation mechanism (not shown) to move gas-distribution fixture **130** from position **138.1** to position **138.2** or to move wafer holder **120** from position **138.2** to **138.1**. In either case, this movement places gas-distribution surface **132.3** one-to-five millimeters from an upper most surface of substrate **200**. In this exemplary position, a lower-most surface of surface-projection member **134** contacts the upper surface of support platform **124**, with the inner chamber bounded by gas-distribution surface **132.3**, surface-projection member **134**, and the upper surface of support platform **124**.

[**0032**] Other embodiments define in the inner chamber in other ways. For example, some embodiments include a surface-projection member on support platform **124** of wafer holder **120** to define a cavity analogous in structure and/or function to cavity **134.1**. In these embodiments, the surface-projection member takes the form of a vertical or slanted or curved wall, that extends from support platform **124** and completely around substrate **200**, and the gas-distribution fixture omits a surface-projection member. However, some embodiments include one or more surface-projection members on the gas-distribution fixture and the on the support platform, with the projection members on the fixture mating, engaging, or otherwise cooperating with those on the support platform to define a substantially or effectively closed chamber. In other words, the inner chamber need not be completely closed, but only sufficiently closed to facilitate a desired deposition.

[**0033**] After forming the inner chamber, the exemplary method continues at block **308**. Block **308** entails introducing one or more reactant or precursor gases into the separate chamber. To this end, the exemplary embodiment operates one or more mass-flow controllers, such as controllers **146** and **147**, to transfer gases in controlled quantities and temporal sequences from gas sources, such as sources **144** and **147**, through gas line **142** and fixture **130** into the separate chamber.

[**0034**] Notably, the inner chamber is smaller in volume than chamber **100** and thus requires less gas and less fill time to achieve desired chemical concentrations (assuming all other factors equal.) More precisely, the exemplary embodiment provides an inner chamber with an empty volume in the range of 70 to 350 cubic centimeters, based on a 1-to-5 millimeter inner-chamber height and a fixture with a 30-centimeter diameter. Additionally, the number and arrangement of holes in the fixture as well as the placement of the holes close to the substrate, for example within five millimeters of the substrate, promote normal gas incidence and uniform distribution of gases over the targeted portion of substrate **200**.

[**0035**] Block **310** entails allowing the gases to react with each other and/or the heated substrate to deposit a layer of material on targeted portions of the substrate. It is expected that the resulting layer will exhibit a highly uniform thickness across the entire substrate because of the more uniform gas distribution.

[**0036**] Next, as block **312** shows, the exemplary method entails evacuating gaseous waste or by-products produced during the deposition. To this end, the exemplary embodiment, activates vacuum pump **160** to pump gaseous waste from the inner chamber through gas-distribution fixture **130**. In some embodiments, pumps **150** and **160** are operated concurrently to establish initial pressure conditions and to evacuate the inner and outer chambers after deposition.

[**0037**] In block **314**, the system opens the separate chamber. In the exemplary embodiment, this entails automatically or manually moving gas-distribution fixture **130** to position **138.1**. Other embodiments, however, move the wafer holder or both the fixture and the wafer holder. Still other embodiments may use multipart collar or gas-confinement members which are moved laterally relative the wafer holder or gas-distribution fixture to open and close an inner chamber.

[**0038**] In block **316**, substrate **200** is unloaded from chamber **110**. Some embodiments remove the substrate manually, and others remove it using an automated wafer transport system.

[**0039**] **FIG. 4** shows a conceptual representation of another exemplary chemical-vapor-deposition system **400** incorporating teachings of the present invention. System **400** includes a rectangular outer chamber **410** which encloses four deposition stations **420**, **422**, **424**, and **426**, loaded with respective substrates **200**, **202**, **204**, and **206**. Although the figure omits numerous components for clarity, each depo-

sition station is structurally and operationally analogous to system **100** in **FIG. 1**. In the exemplary embodiment, two or more of the stations are operated in parallel. Additionally, other embodiments of this multi-station system arrange the stations in a cross formation, with each station confronting a respective lateral face of the chamber. Still other embodiments use different outer chamber geometries, for example cylindrical or spherical.

CONCLUSION

[**0040**] In furtherance of the art, the inventor has presented new systems, methods, and apparatuses for chemical-vapor deposition. One exemplary system includes an outer chamber, a substrate holder, and a unique gas-distribution fixture. The fixture includes a gas-distribution surface having holes for dispensing a gas and a gas-confinement member that engages, or otherwise cooperates with the substrate holder to form an inner chamber within the outer chamber.

[**0041**] Notably, the inner chamber not only consumes less gas during deposition to reduce deposition waste and cost, but also facilitates rapid filling and evacuation to reduce deposition cycle times (with all other factors being equal.) The inner chamber also places the gas-distribution fixture within several millimeters of a substrate on the substrate holder, promoting normal gas incidence across the chamber and thus uniform deposition thickness.

[**0042**] The embodiments described above are intended only to illustrate and teach one or more ways of practicing or implementing the present invention, not to restrict its breadth or scope. The actual scope of the invention, which embraces all ways of practicing or implementing the invention, is defined only by the following claims and their equivalents.

1. A chemical-vapor-deposition system comprising:

a first chamber for confining gases; and

a second chamber within the first chamber for at least partially containing a substrate during deposition.

2. The system of claim 1, wherein the first chamber is a right cylindrical chamber.

3. The system of claim 1, wherein the second chamber comprises a surface of a substrate-support structure.

4. The system of claim 3, wherein the second chamber further comprises a gas-distribution fixture for atomic-layer deposition, the fixture confronting the surface of the substrate-support structure and comprising:

a non-reactive plate including a plurality of holes; and

a wall surrounding at least a portion of the plate.

5. A chemical-vapor deposition system comprising:

first means for confining one or more gases;

second means for confining one or more gases, the first means at least partly contained within the first means; and

third means for confining one or more gases, the third means at least partly contained within the first means.

6. A gas-distribution fixture for atomic-layer deposition, the fixture comprising:

a non-reactive plate including a plurality of holes; and

a wall surrounding at least a portion of the plate;

7. The fixture of claim 6, wherein the wall consists essentially of a material that is different from that of the non-reactive plate.

8. The fixture of claim 6, wherein the non-reactive plate consists essentially of silicon and a silicon oxide.

9. The fixture of claim 6, wherein the wall has a uniform height measured from a surface of the non-reactive plate.

10. The fixture of claim 6, wherein the wall consists essentially of a material that is different from that of the second non-metallic plate.

11. The fixture of claim 6, wherein the wall consists essentially of a stainless steel.

12. The fixture of claim 6, wherein the non-reactive plate is formed in a method comprising:

forming one or more channels in a first plate;

forming two or more holes in a second plate;

forming a bond between the first and second plates.

13. A method of making at least a portion of a gas-distribution fixture for a chemical-vapor-deposition system, the method comprising:

forming one or more channels in a first plate;

forming two or more holes in a second plate;

forming a bond between the first and second plates.

14. The method of claim 13, wherein forming one or more channels in the first plate comprises:

masking the first plate to define a respective position of each of the channels; and

etching the masked first plate to form the channels.

15. The method of claim 13, wherein etching the masked first plate comprises wet etching the masked first plate.

16. The method of claim 13, wherein forming the one or more channels comprises forming two or more perpendicular channels.

17. The method of claim 13, wherein forming the one or more channels comprises forming two or more channels having a common width and depth.

18. The method of claim 13, wherein forming holes in the second plate comprises:

masking the second plate to define a respective size, shape, and position of each of the holes; and

etching the masked second plate to form the channels.

19. The method of claim 13 wherein etching the masked second plate comprises wet etching the masked first plate.

20. The method of claim 13, wherein forming the holes comprises forming two or more holes of approximately the same shape and size.

21. The method of claim 13, wherein forming the one or more channels comprises forming two or more channels having a common width and depth.

22. The method of claim 13:

wherein the first and second plates consist essentially of silicon; and

wherein forming the bond between the first and second plates comprises:

aligning the first and second plates such that the one or more channels are in fluid communication with the two or more holes; and

using a silicon-wafer bonding technique to effect the bond.

23. The method of claim 13, wherein forming the one or more channels in the first plate occurs after forming the two or more holes in the second plate;

24. A method of making at least a portion of a gas-distribution fixture for a chemical-vapor-deposition system, the method comprising:

forming one or more channels in a first plate;

forming two or more holes in a second plate;

aligning the first and second plates, with at least one of the holes aligned with one of the channels; and

bonding the first and second plates to each other.

* * * * *