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(54) **APPARATUS FOR THE DEPOSITION OF
HIGH DIELECTRIC CONSTANT FILMS**

Related U.S. Application Data

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filed on Oct. 27, 1998, now Pat. No. 6,454,860.

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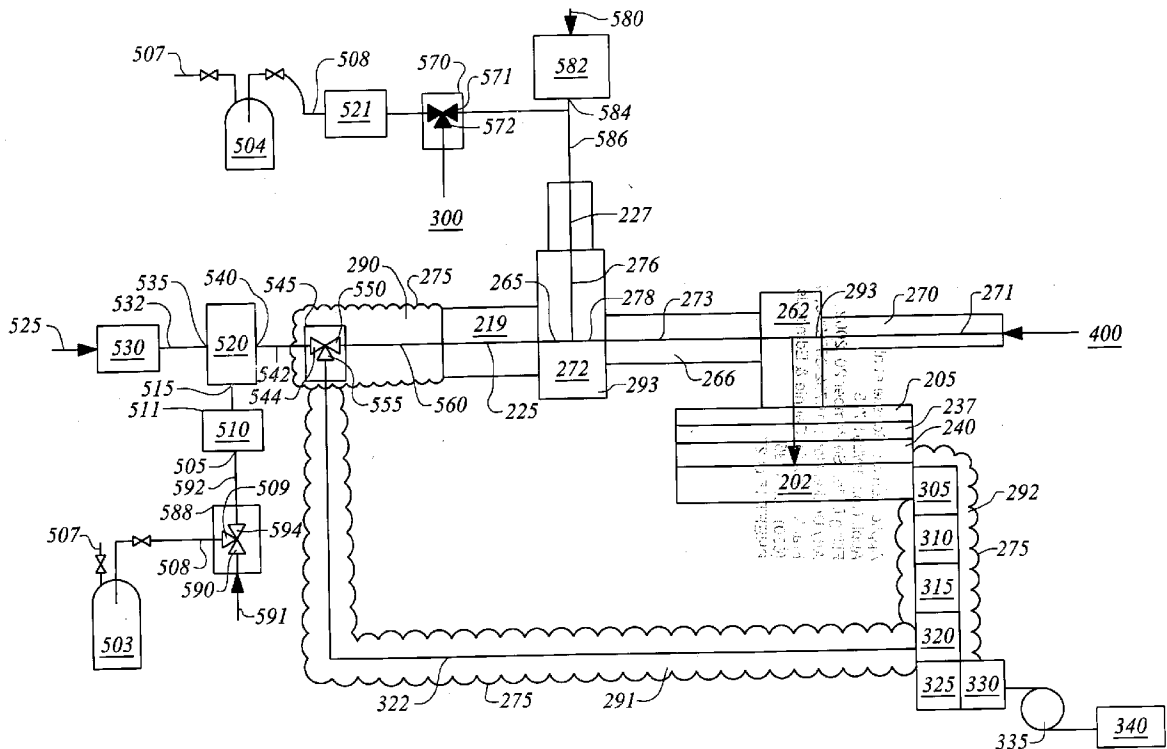
(57) **ABSTRACT**

An integrated deposition system is described that is capable of vaporizing low vapor pressure liquid precursors and conveying the vapor to a processing region to fabricate advanced integrated circuits. The integrated deposition system includes a heated exhaust system, a remote plasma generator, a processing chamber, a liquid delivery system, and a computer control module that together create a commercially viable and production worthy system for depositing high capacity dielectric materials from low vapor pressure precursors.

(73) Assignee: **Applied Materials, Inc.**

(21) Appl. No.: **10/251,715**

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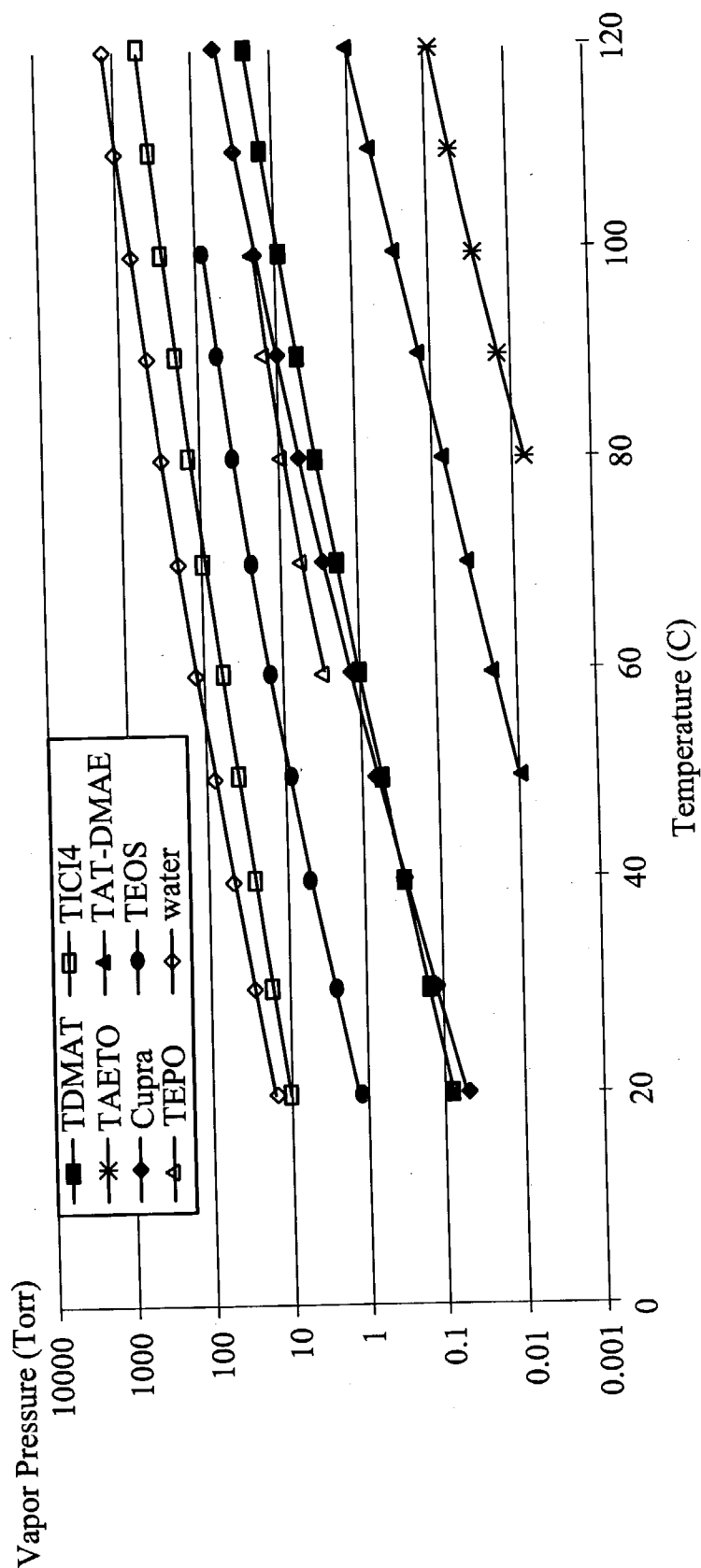
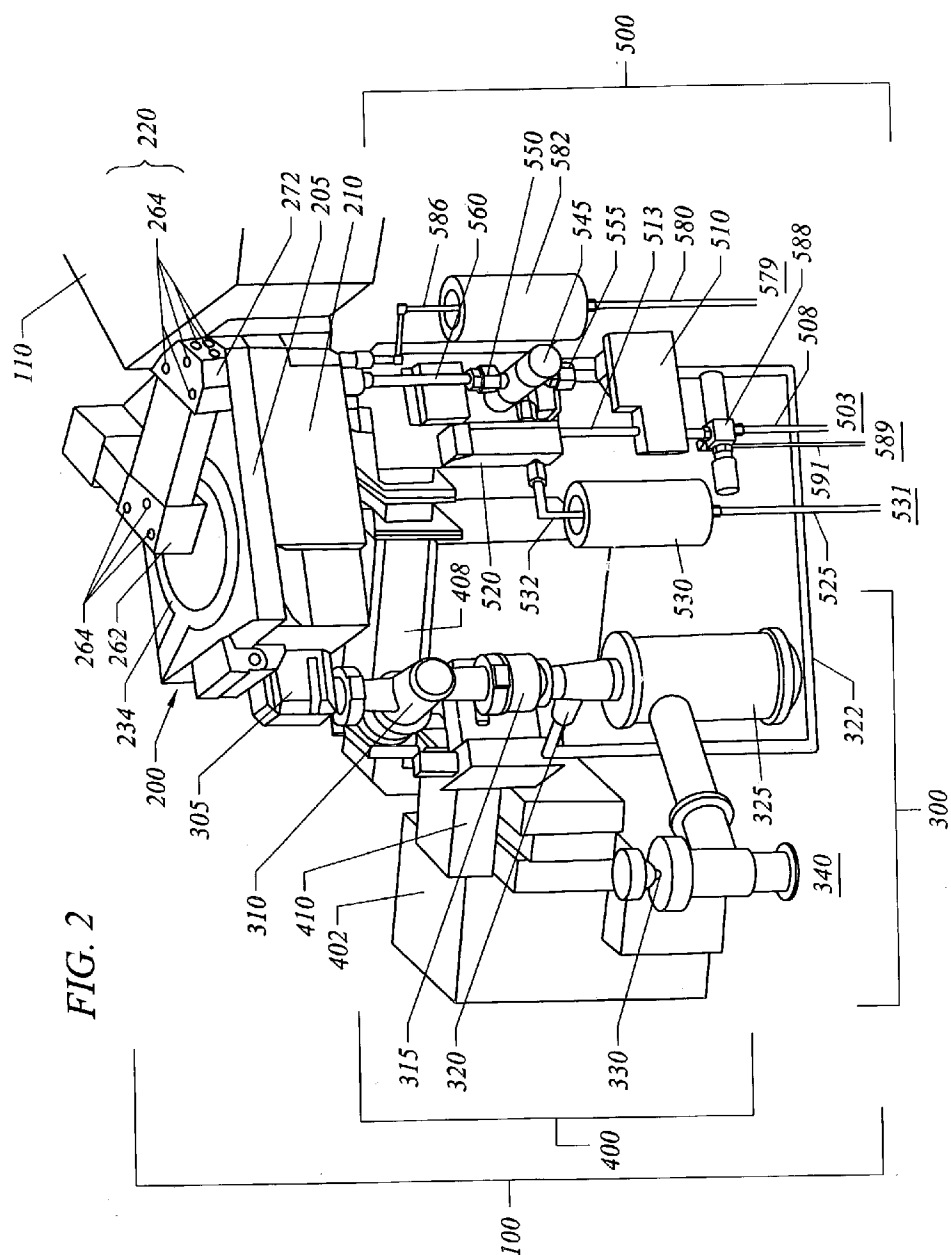


FIG. 1



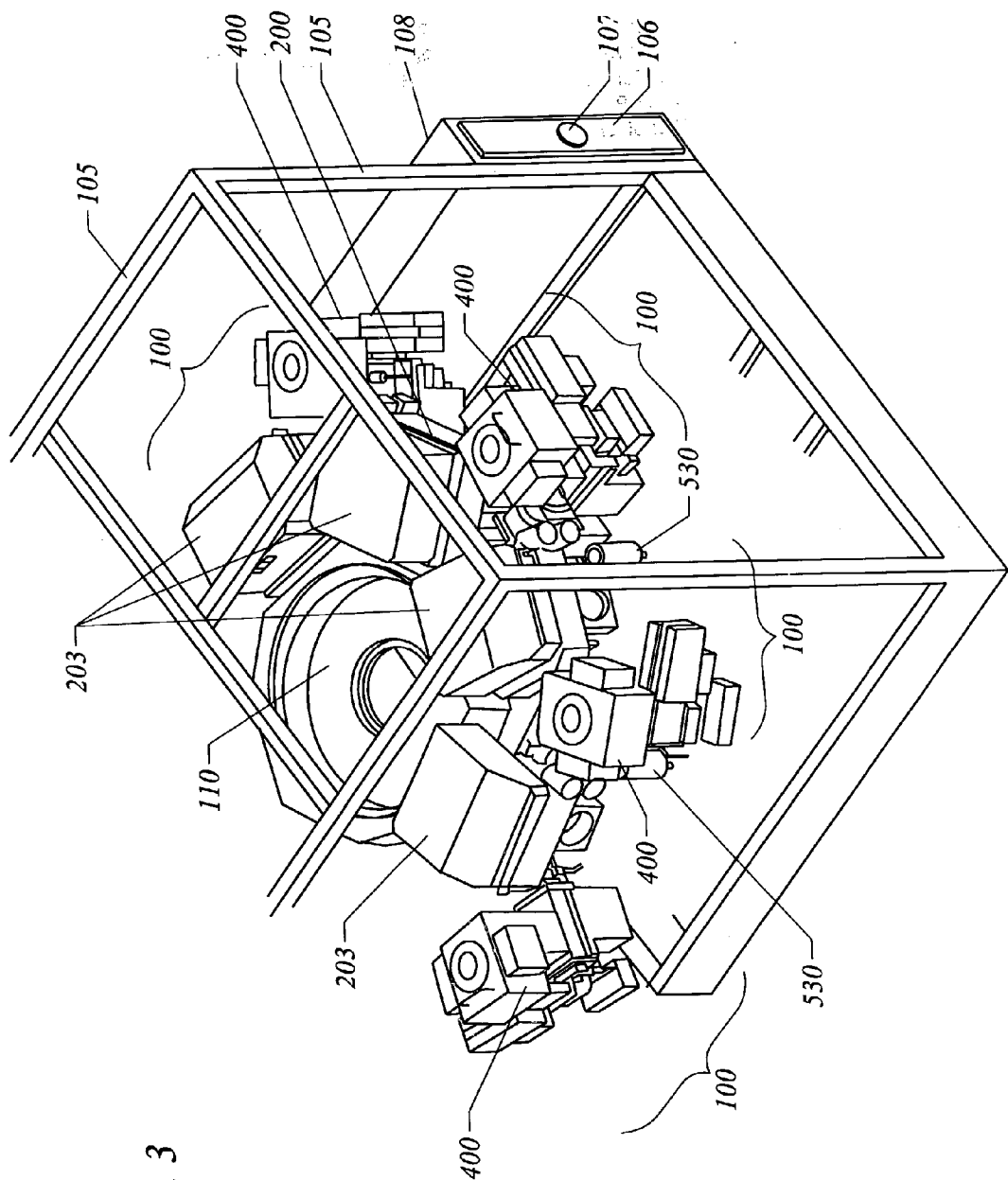


FIG. 3

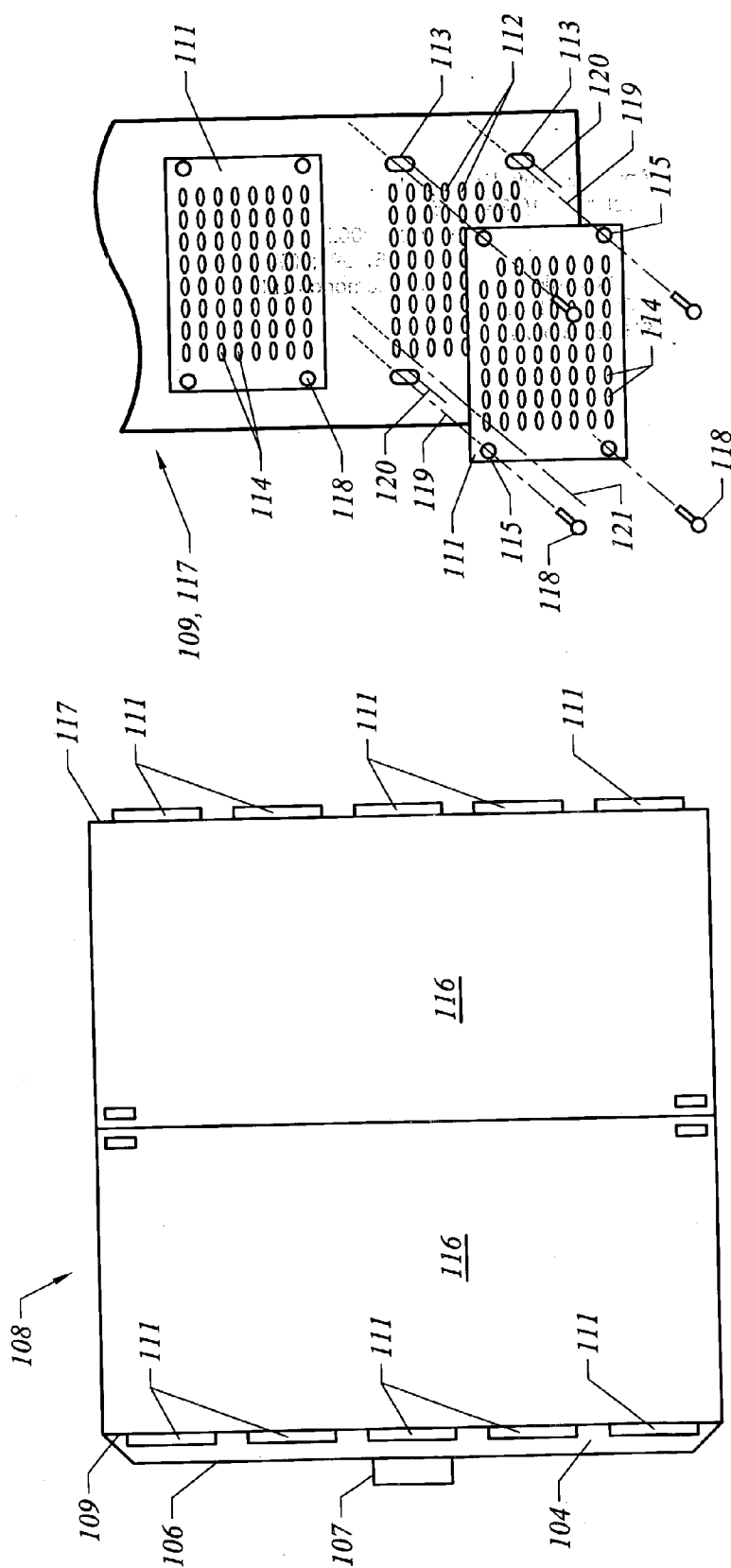


FIG. 5

FIG. 4

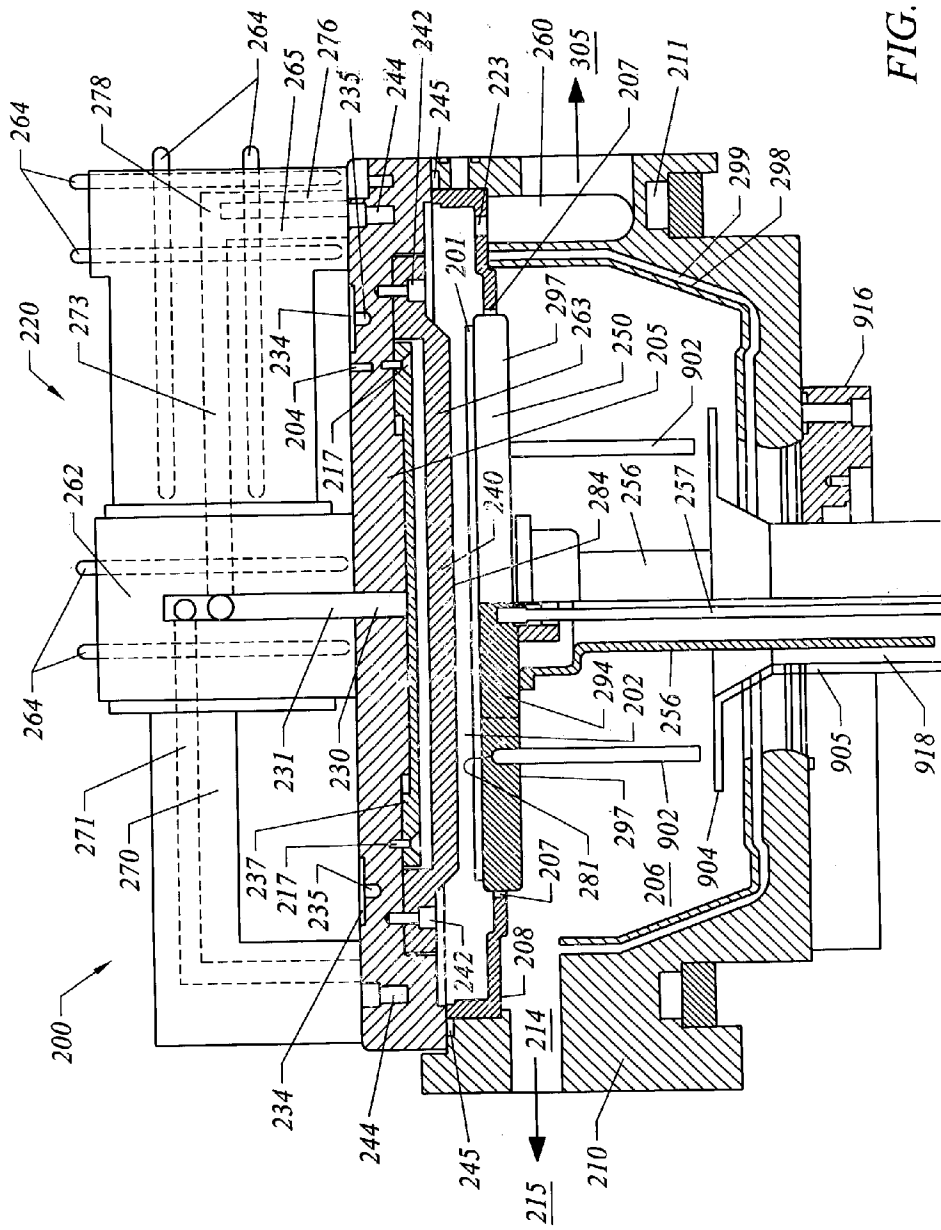


FIG. 6

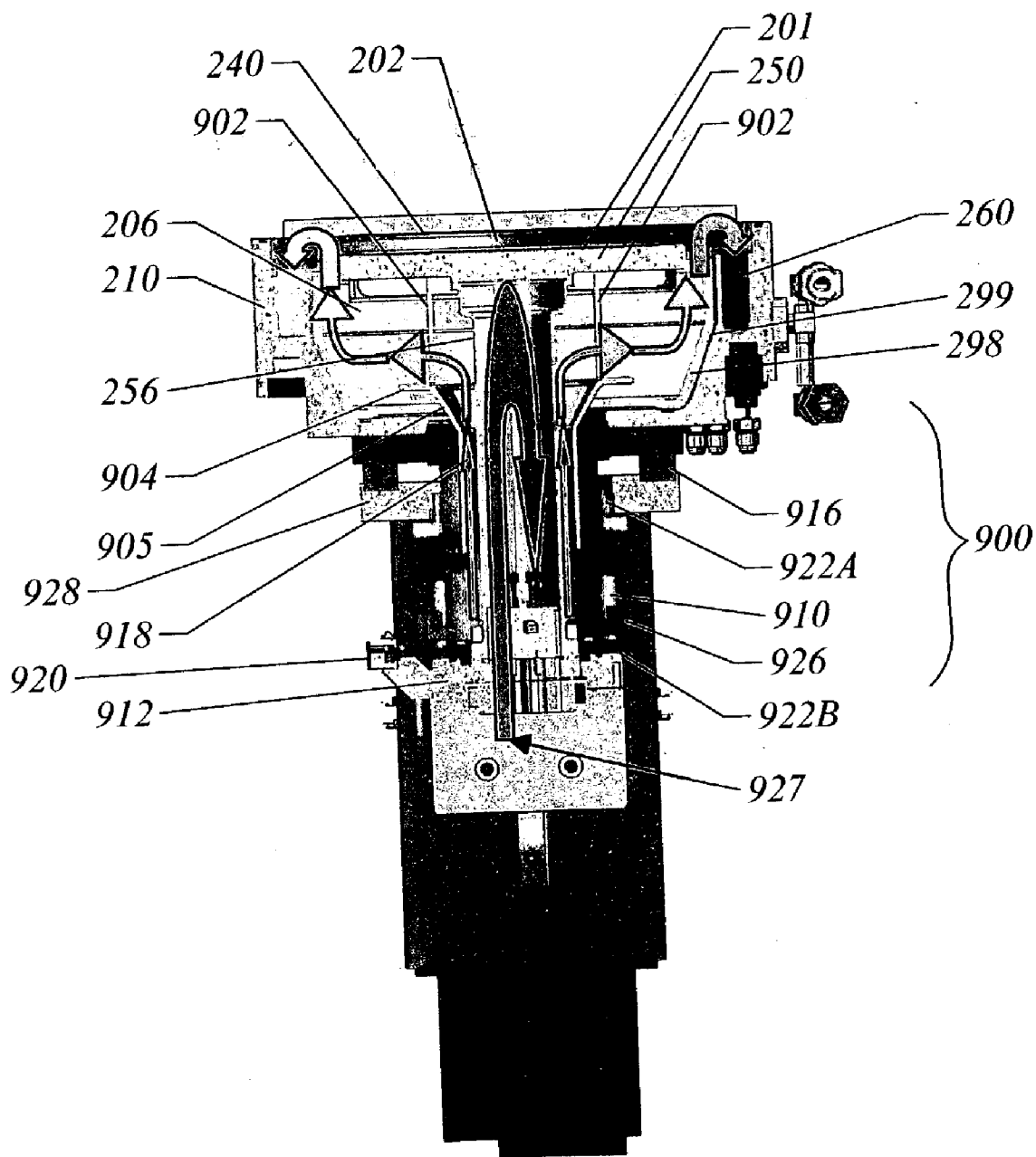


FIG. 7

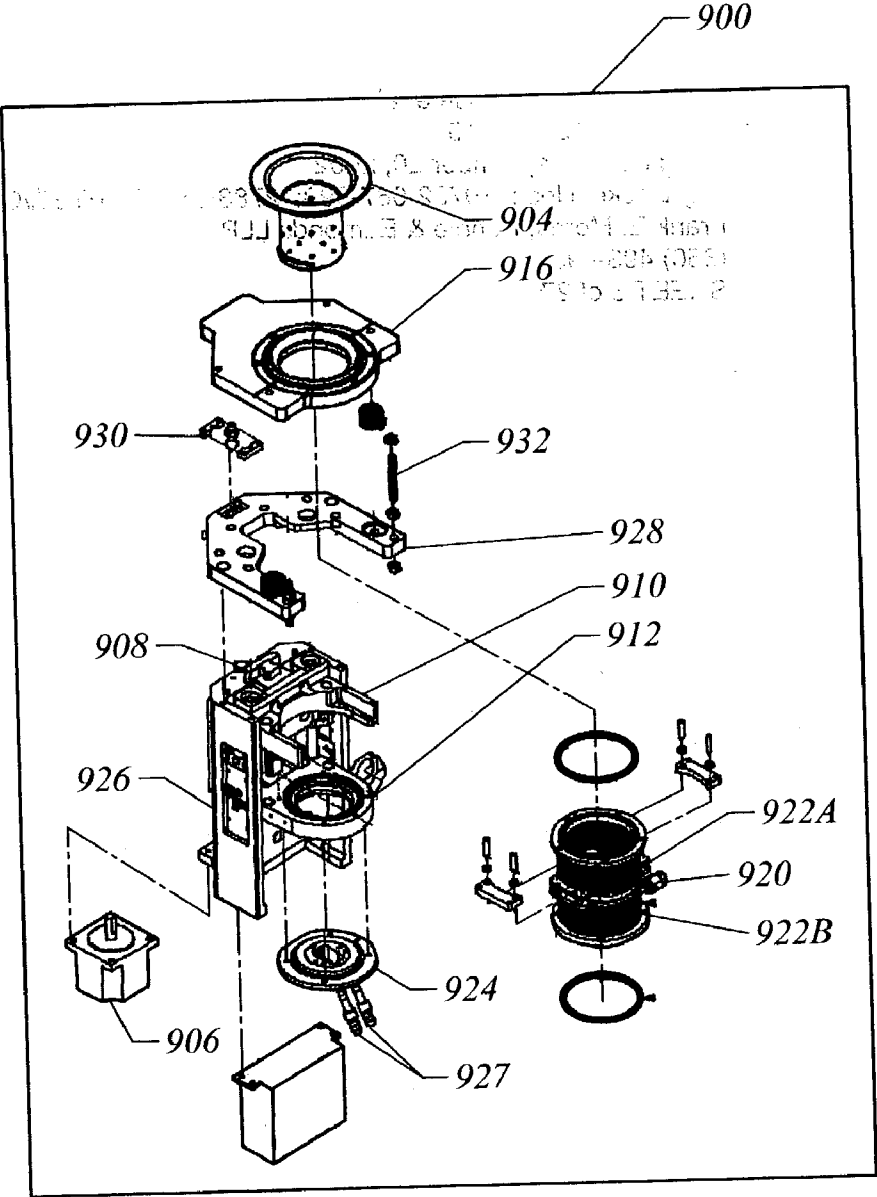


FIG. 8

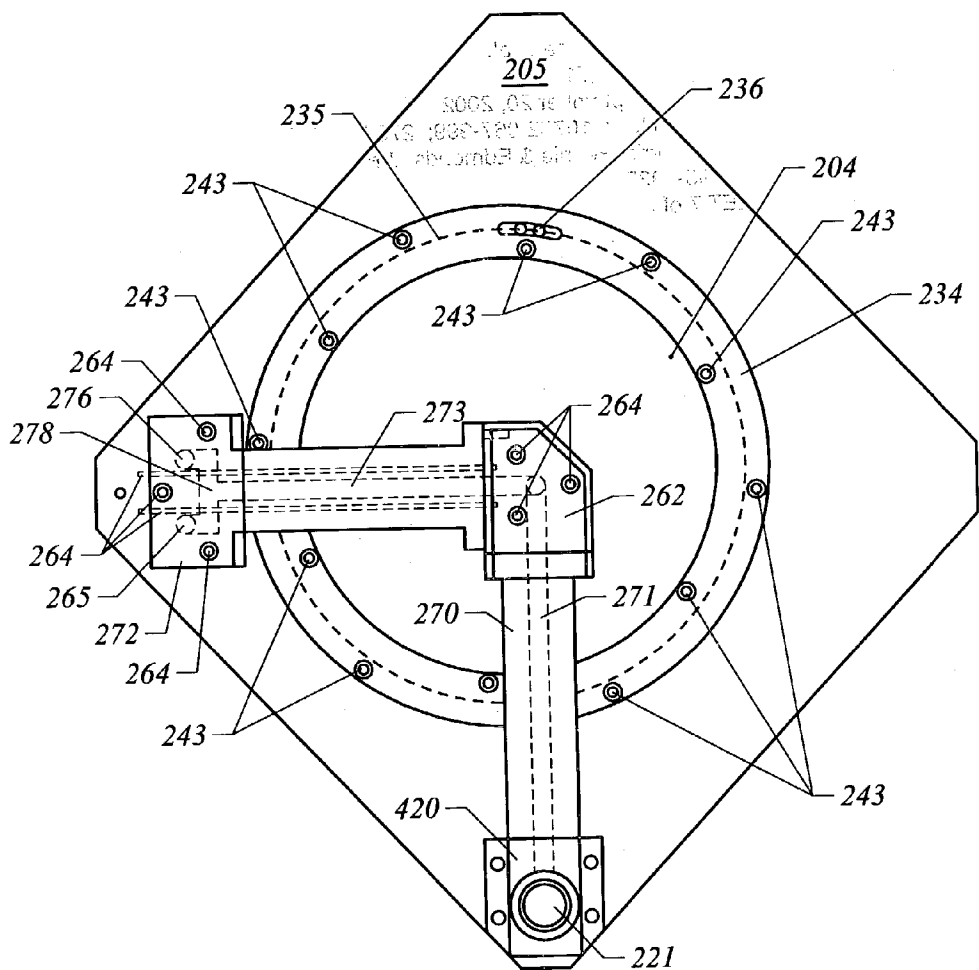
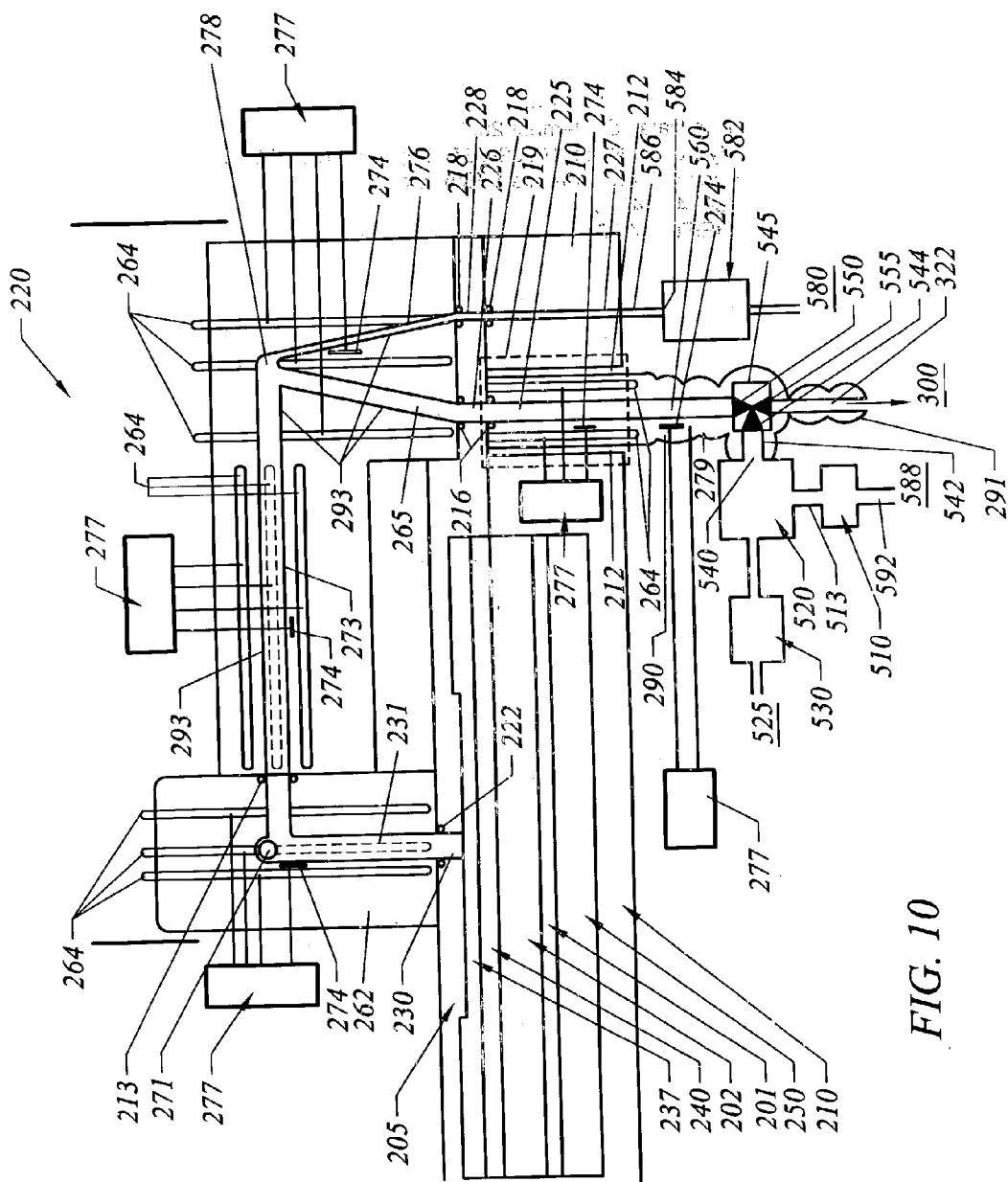


FIG. 9



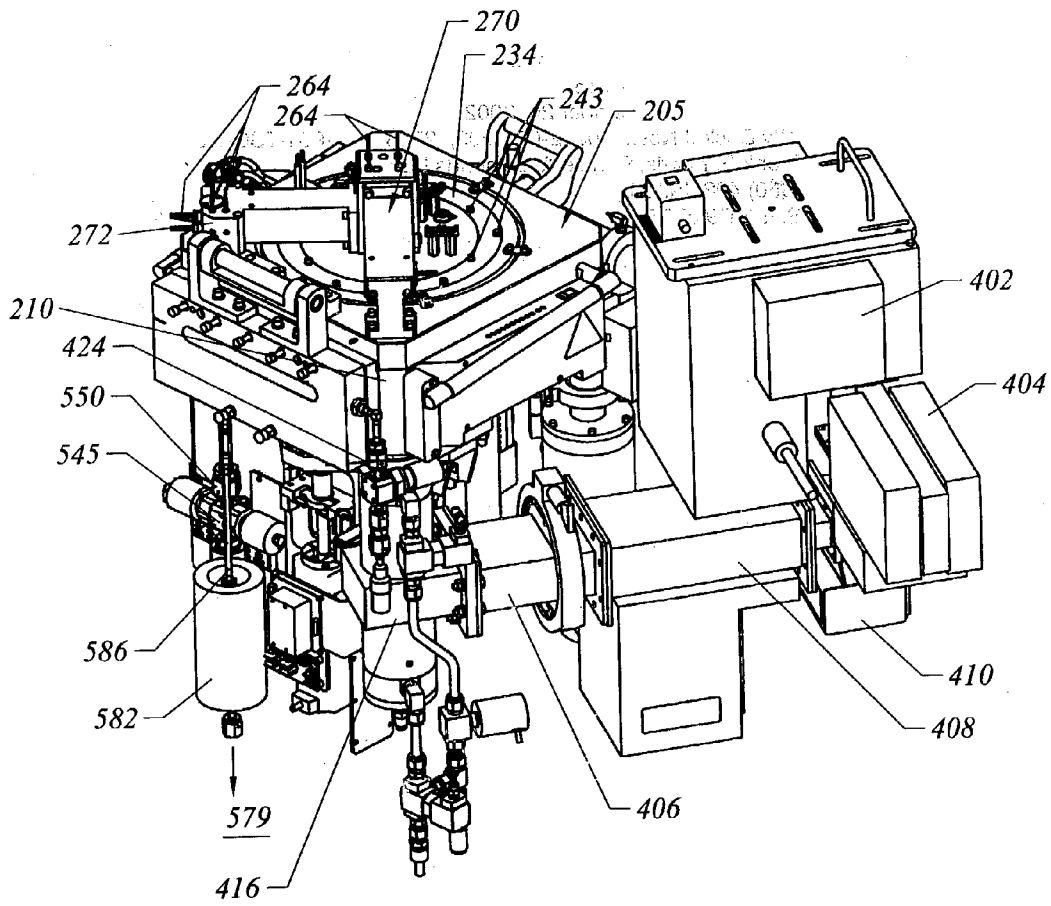


FIG. 11

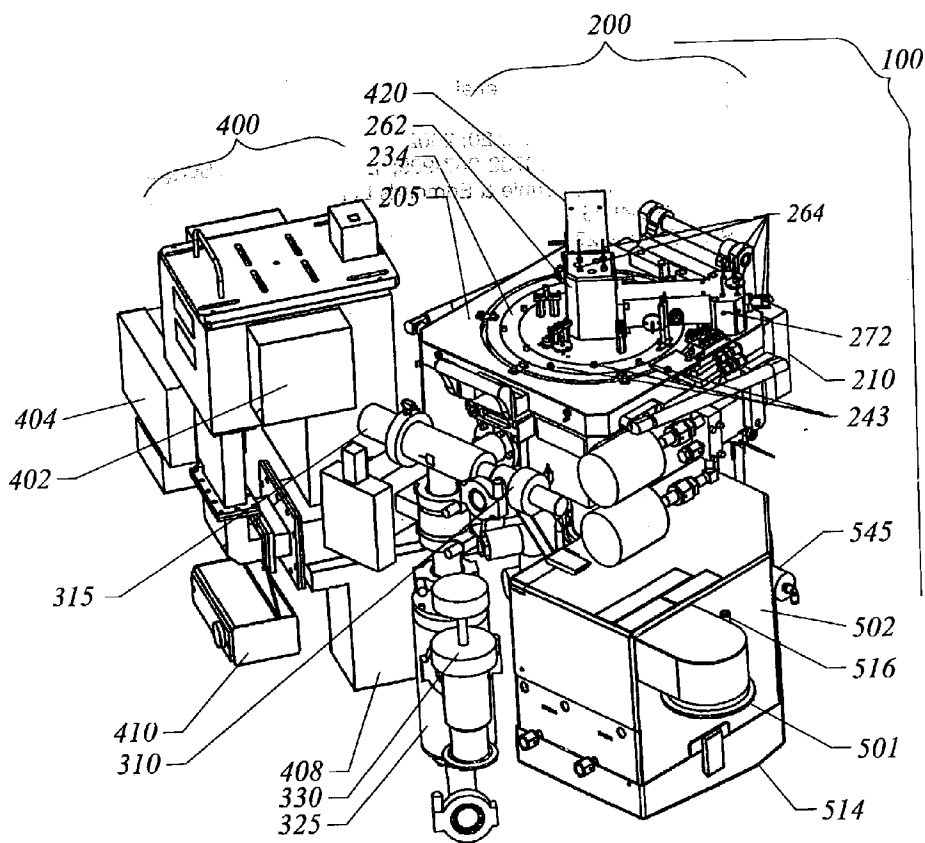


FIG. 12

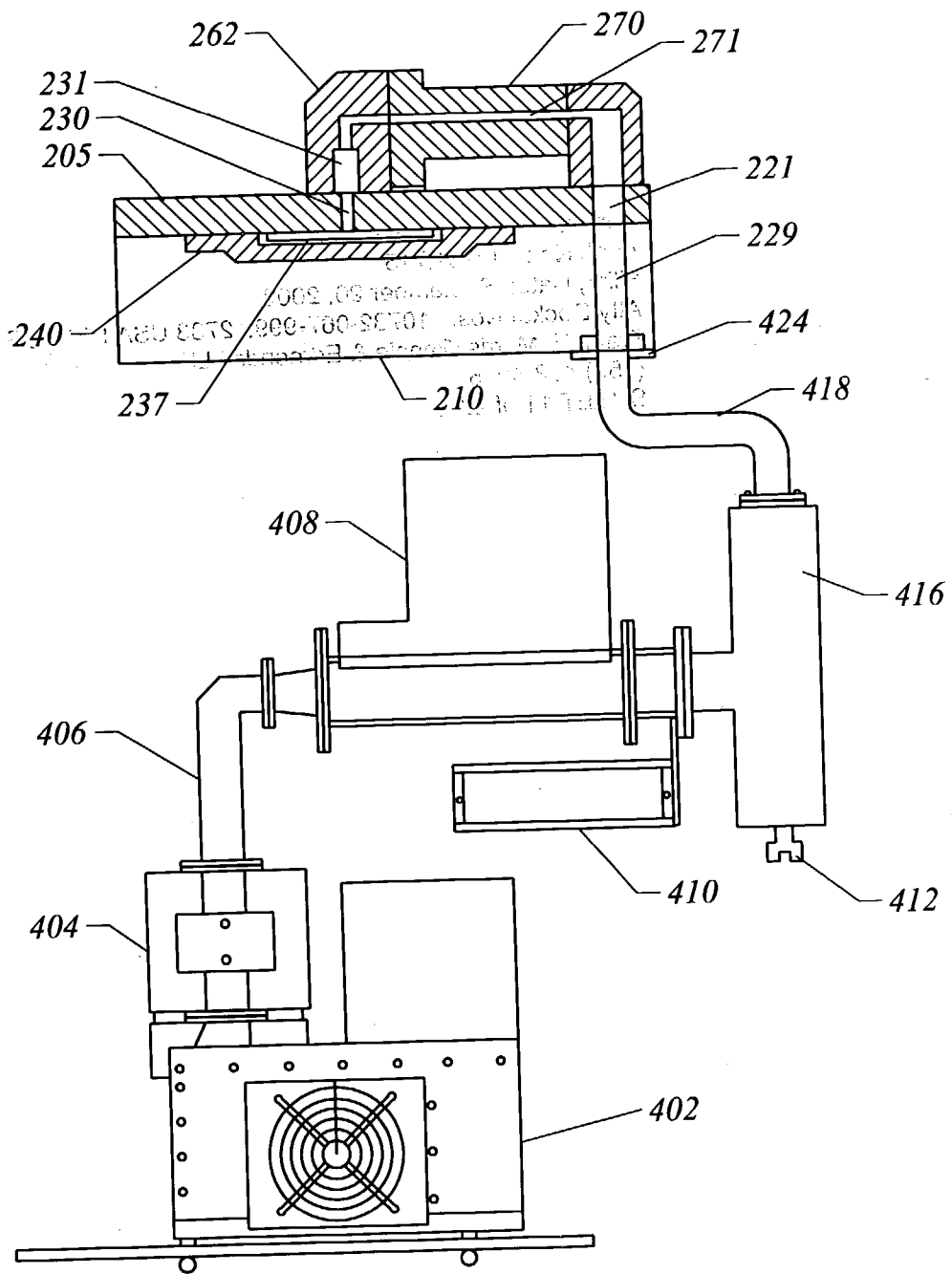


FIG. 13

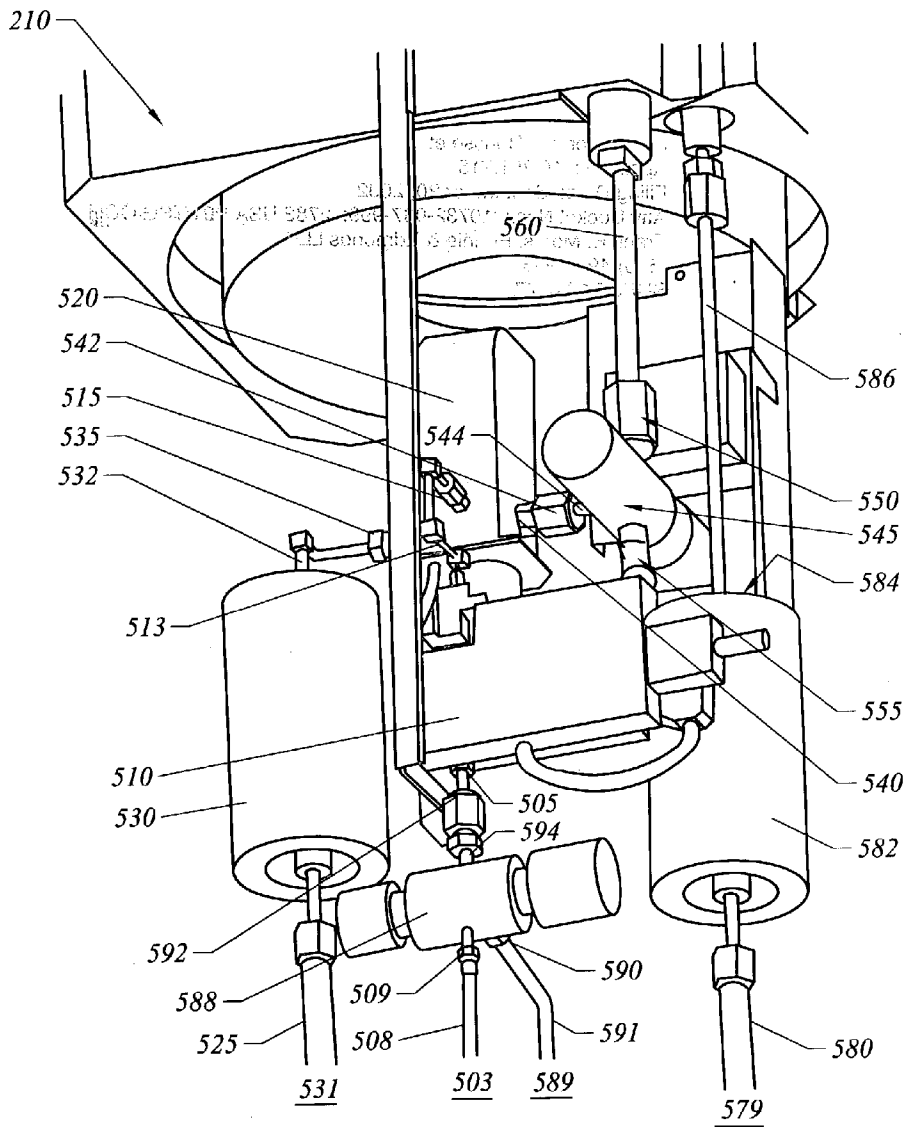


FIG. 14

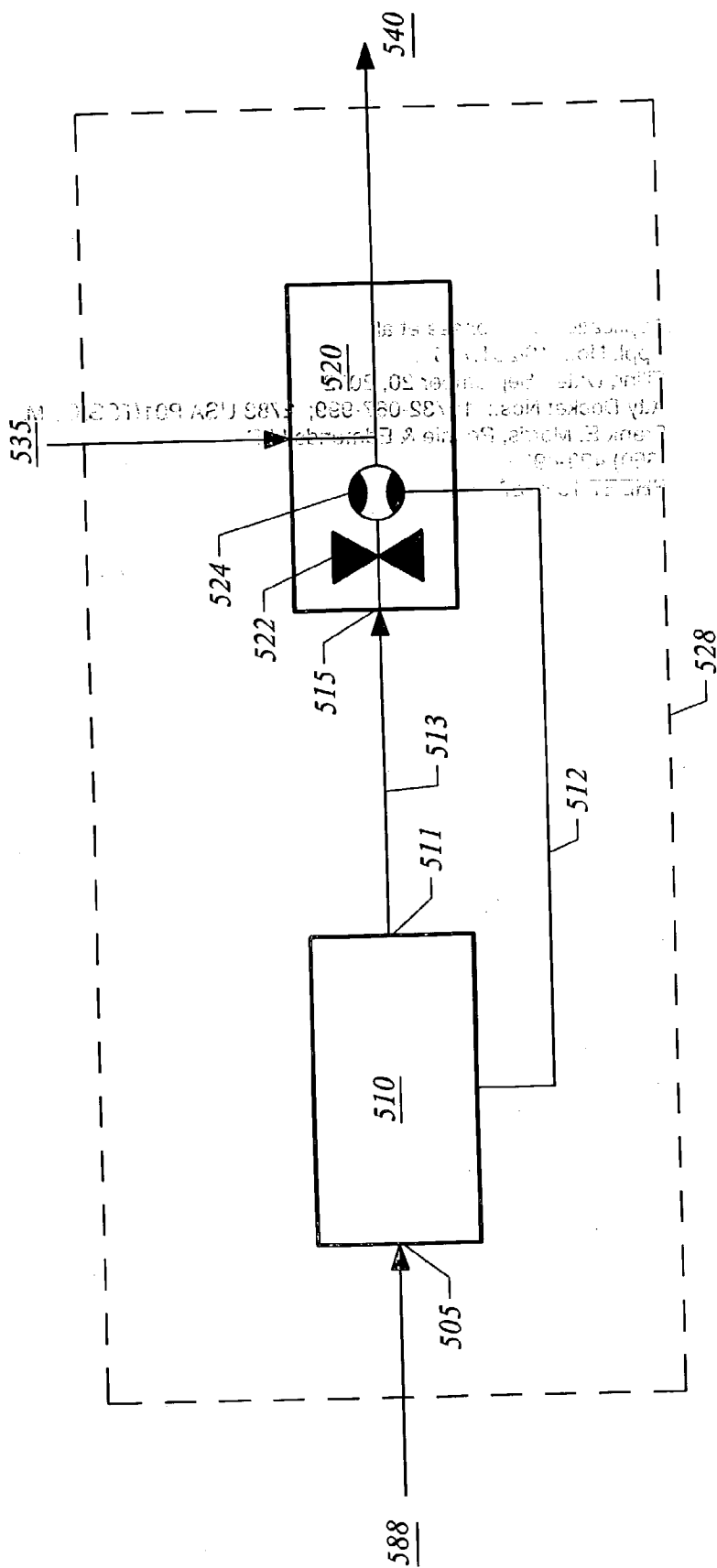
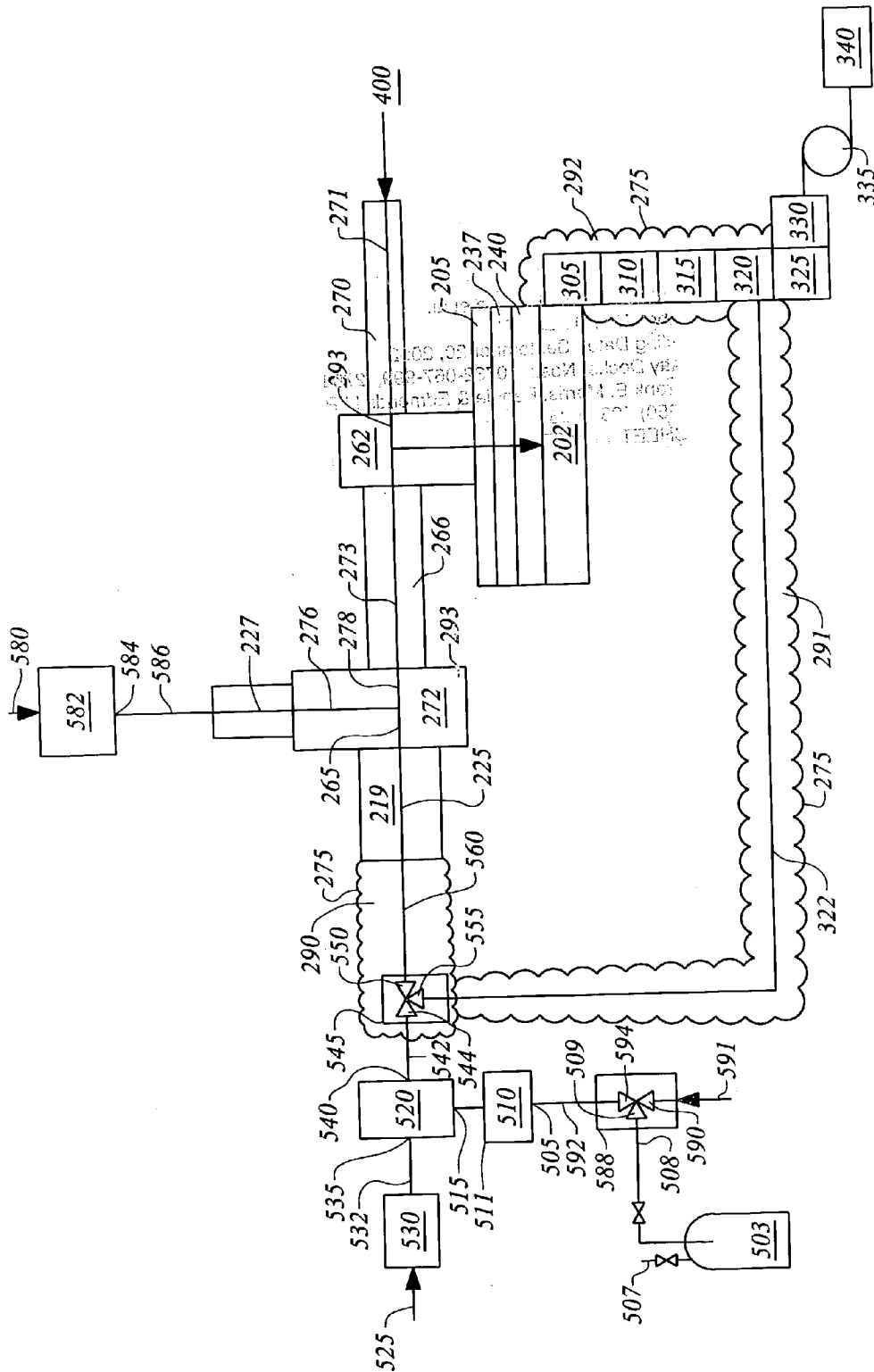


FIG. 15



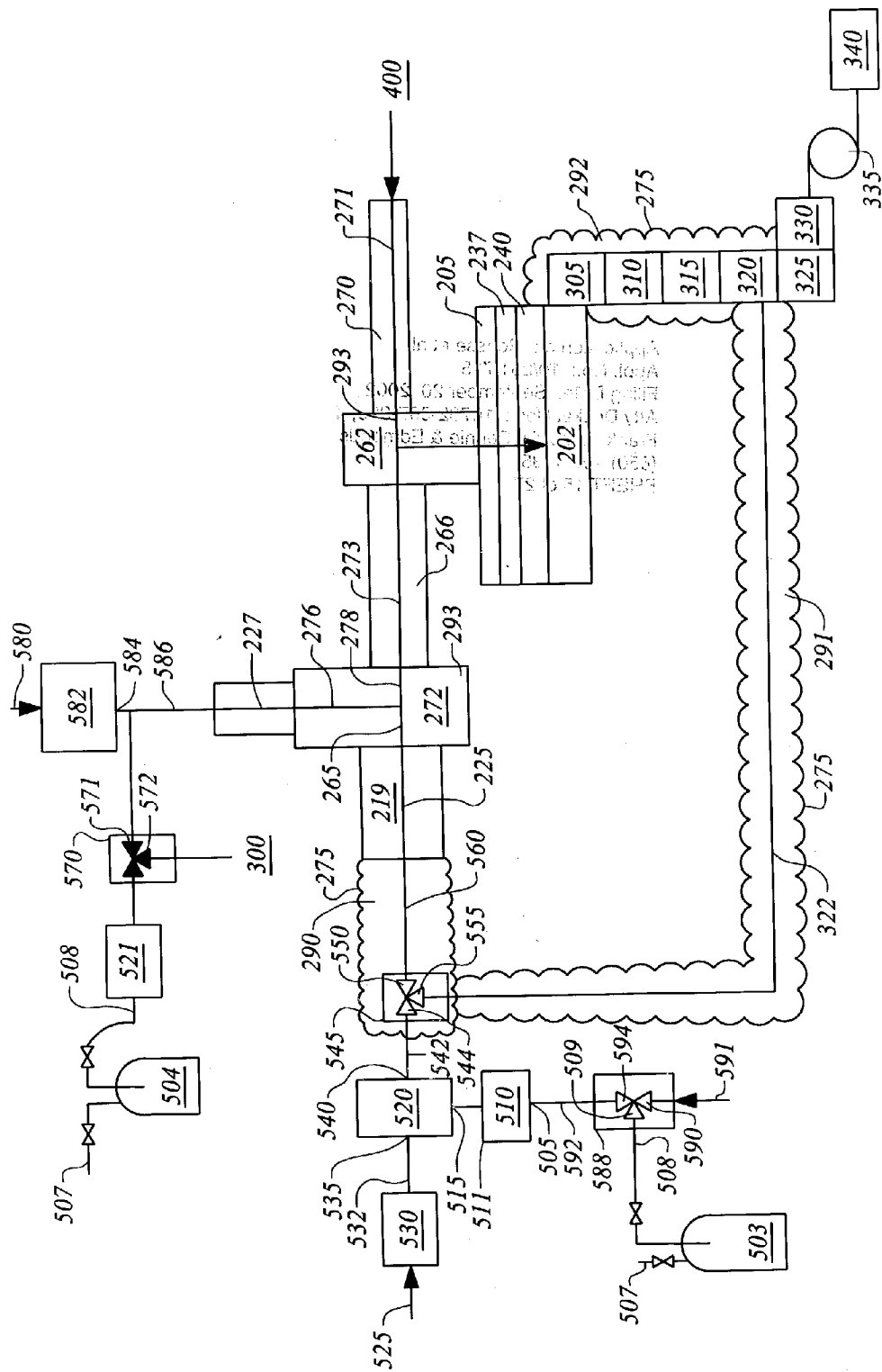


FIG. 17

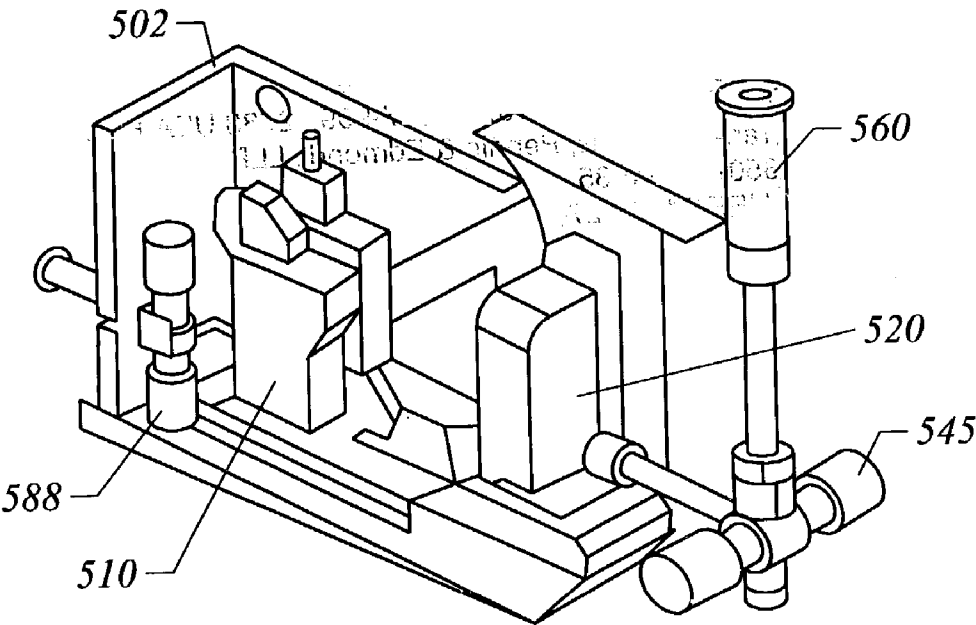
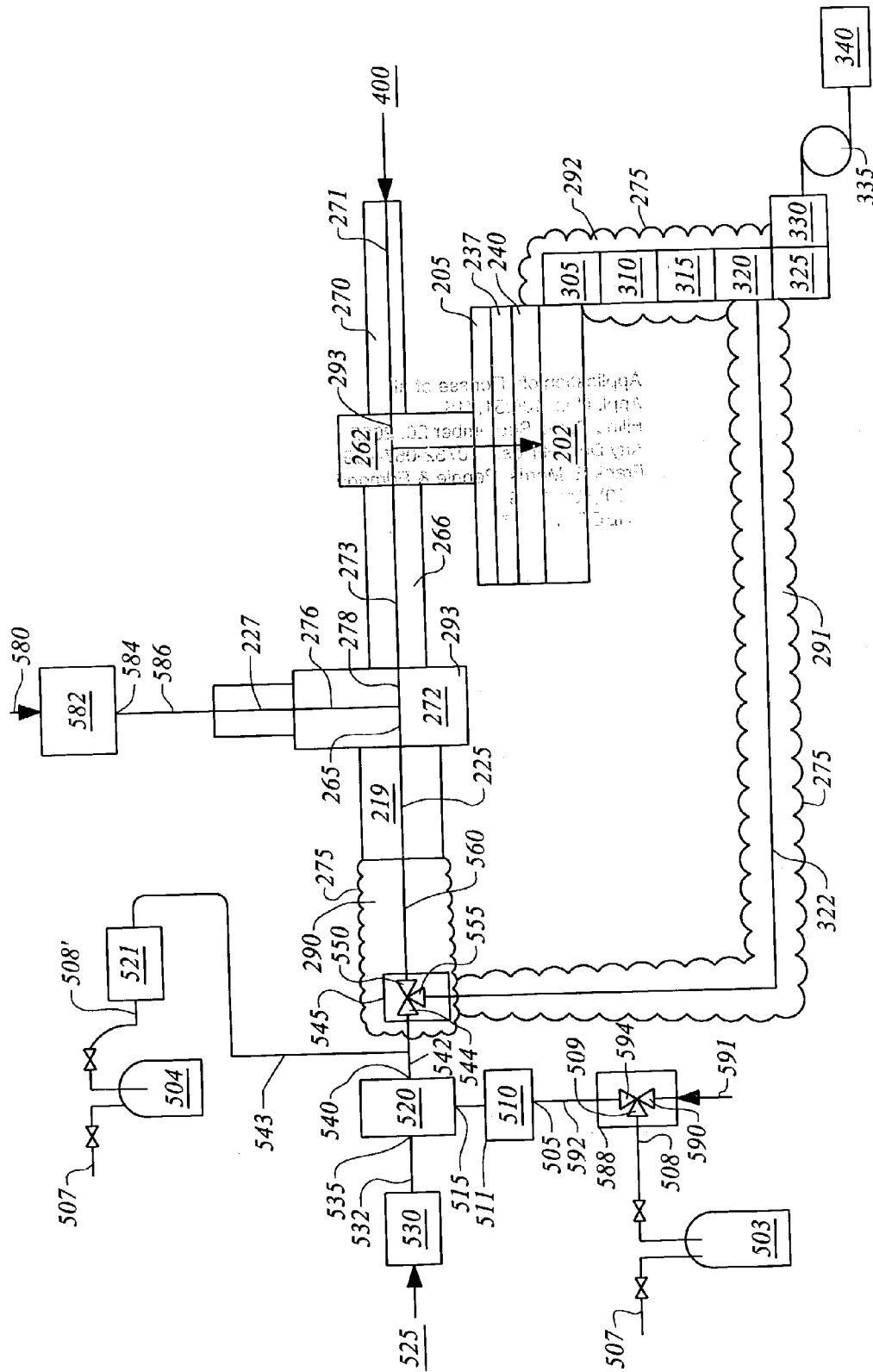


FIG. 18



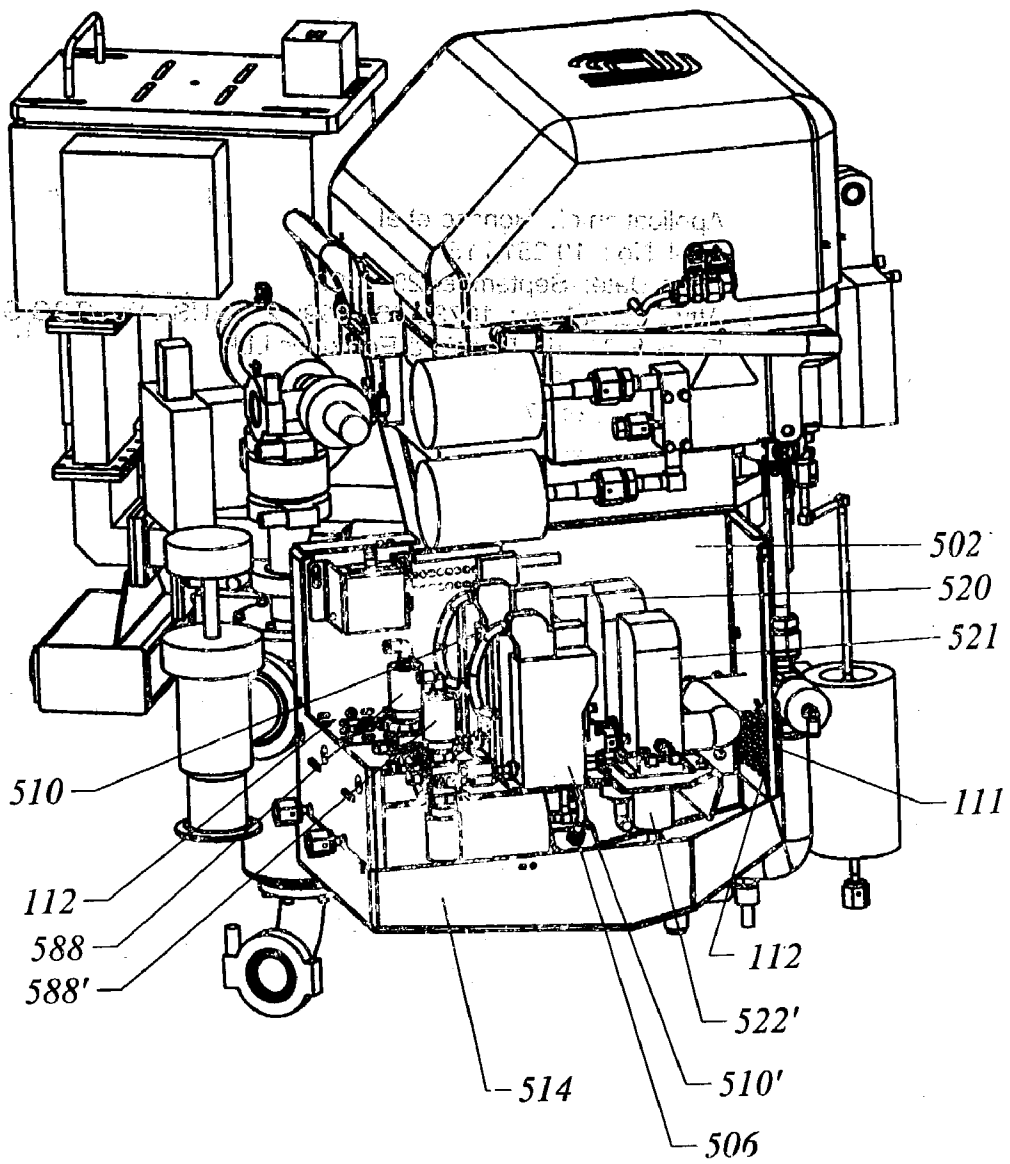


FIG. 20

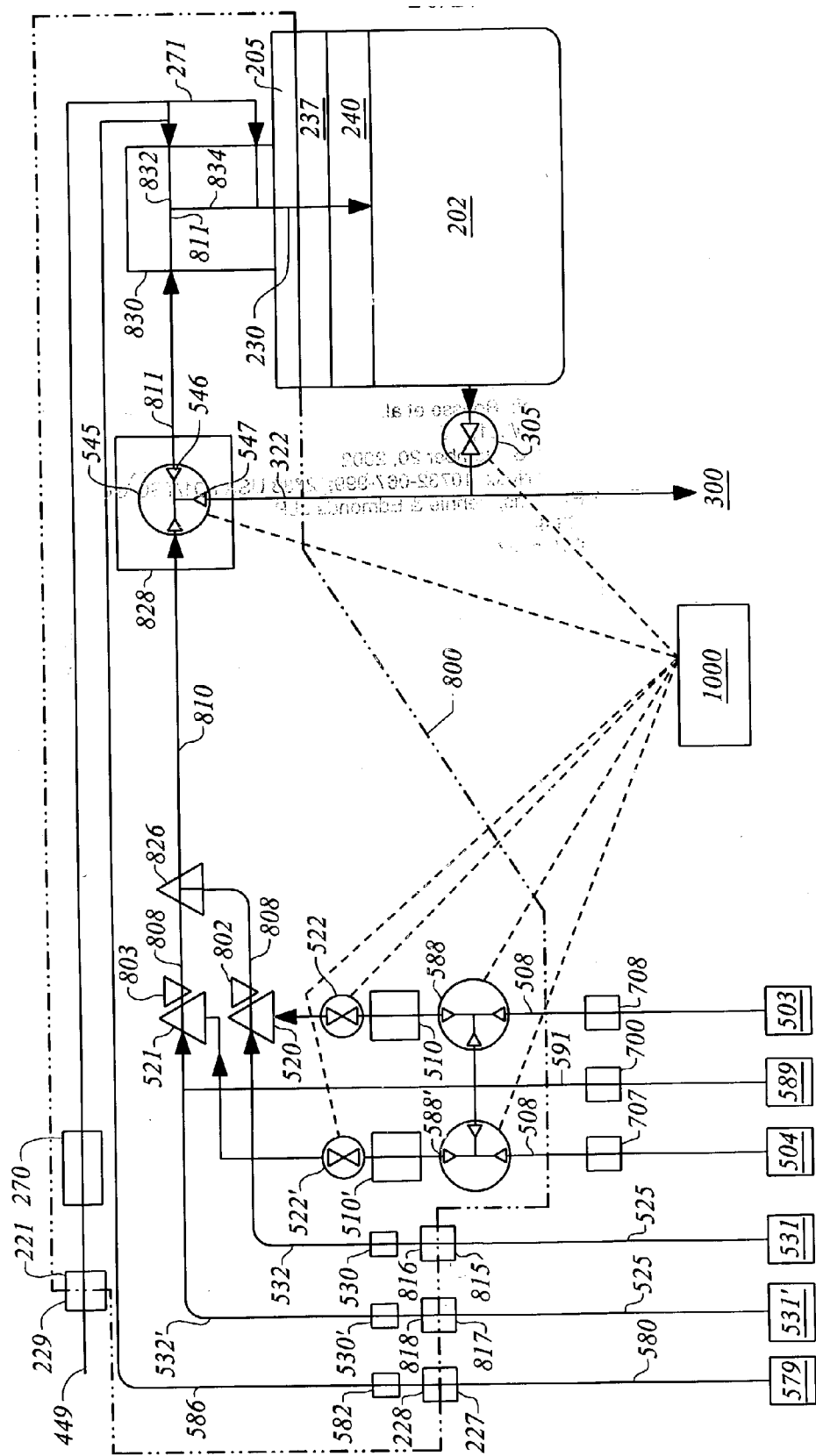


FIG. 21

FIG. 22

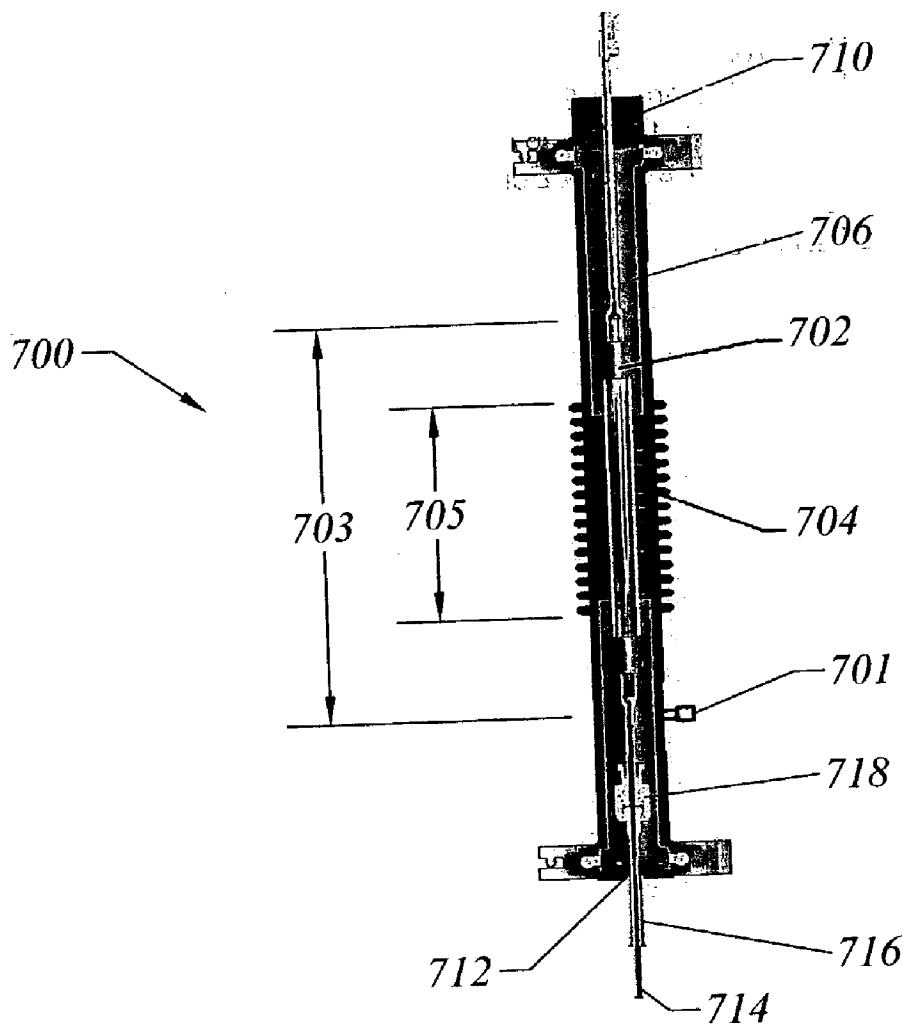


FIG. 23

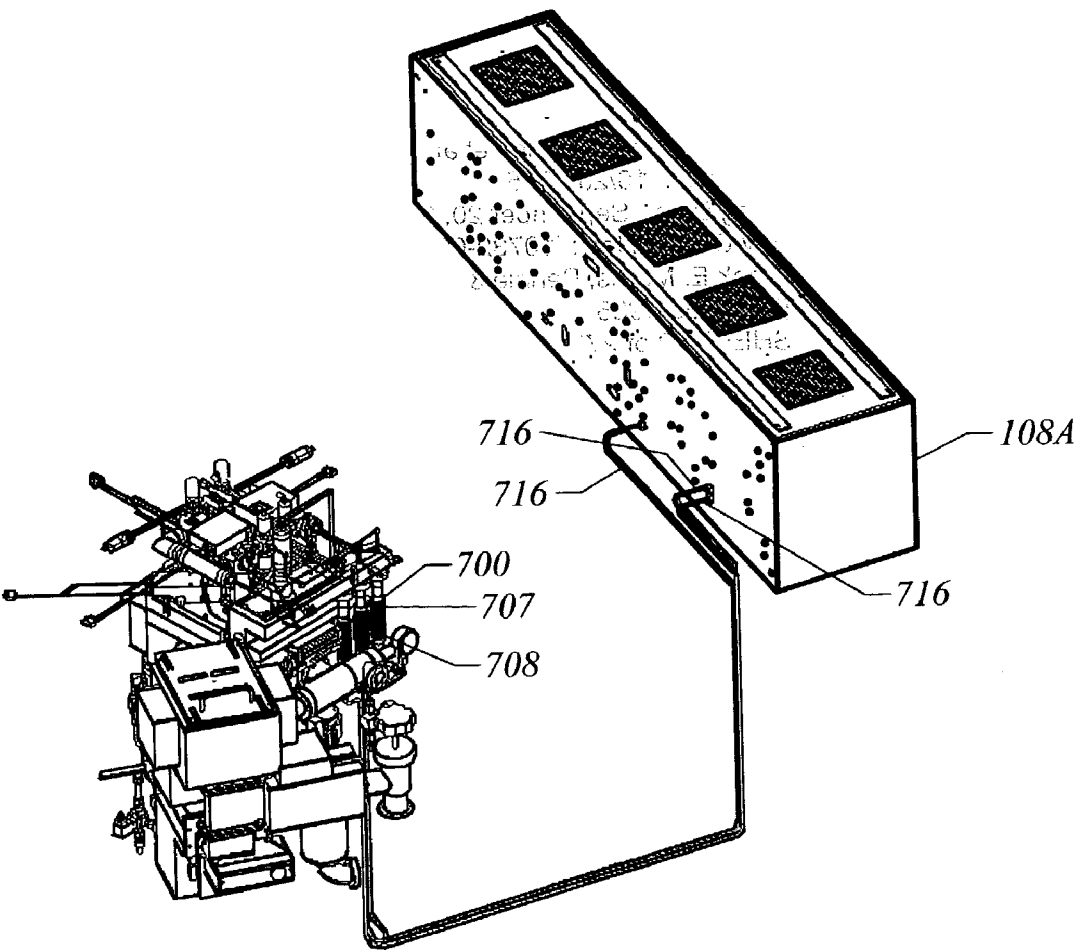


FIG. 24

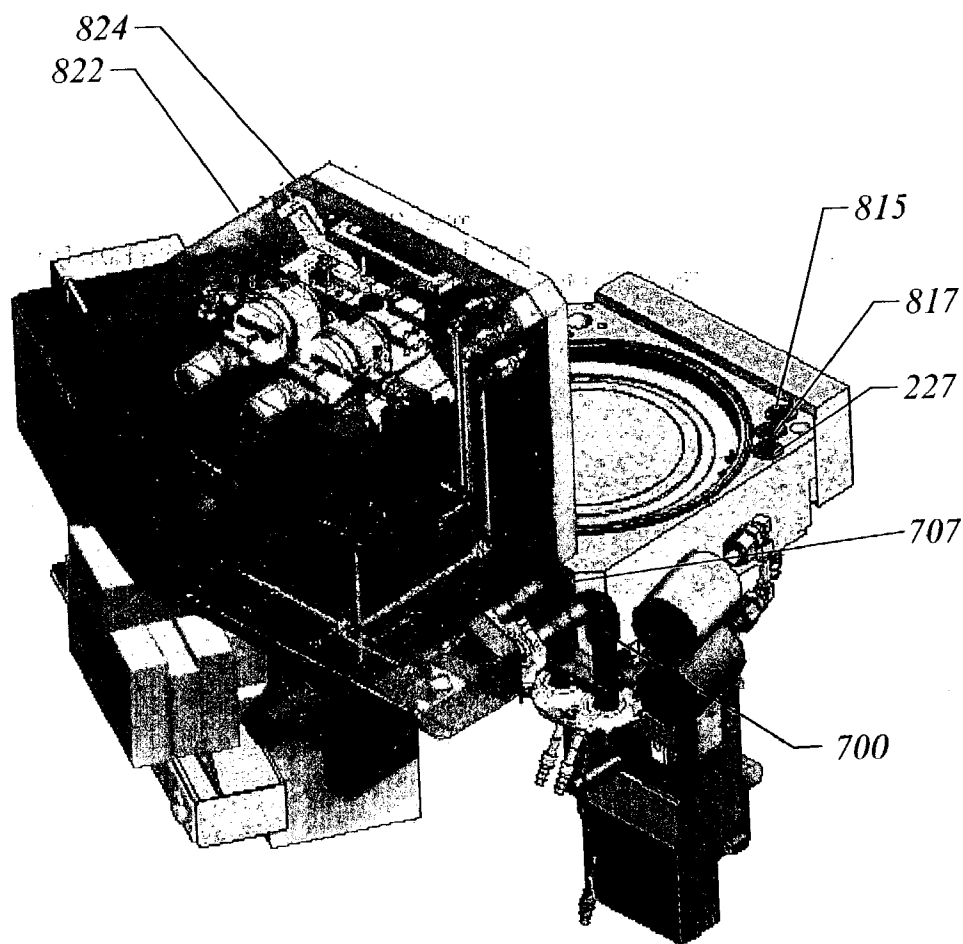


FIG. 25

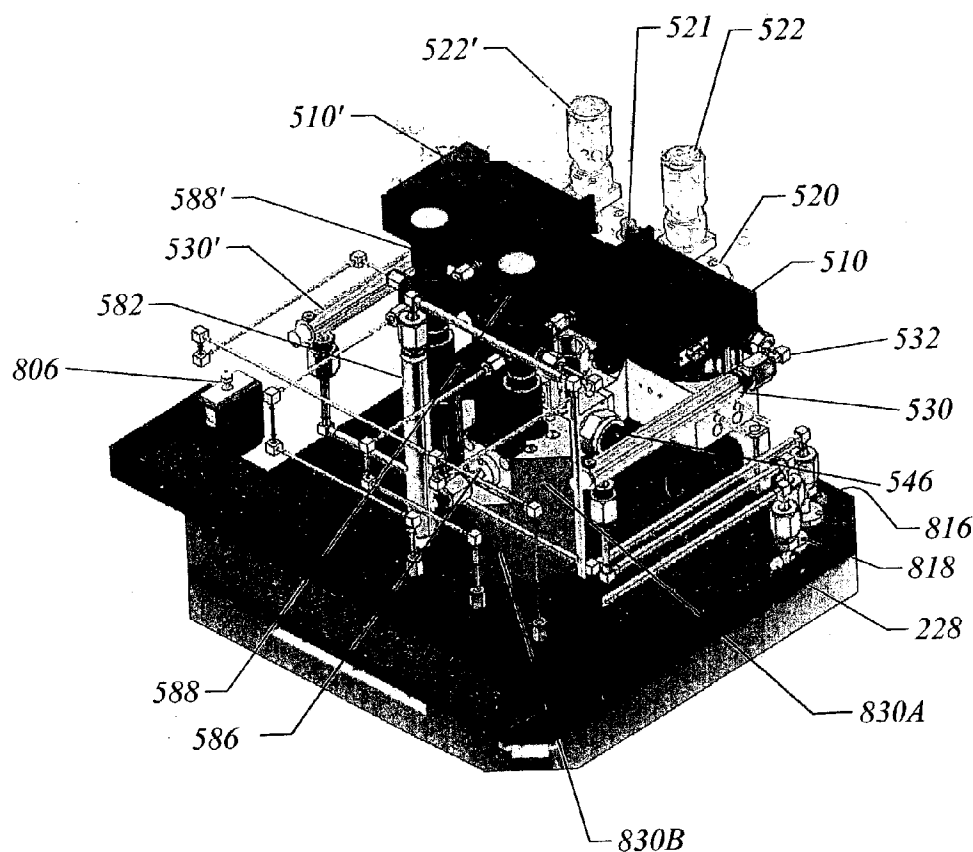


FIG. 26

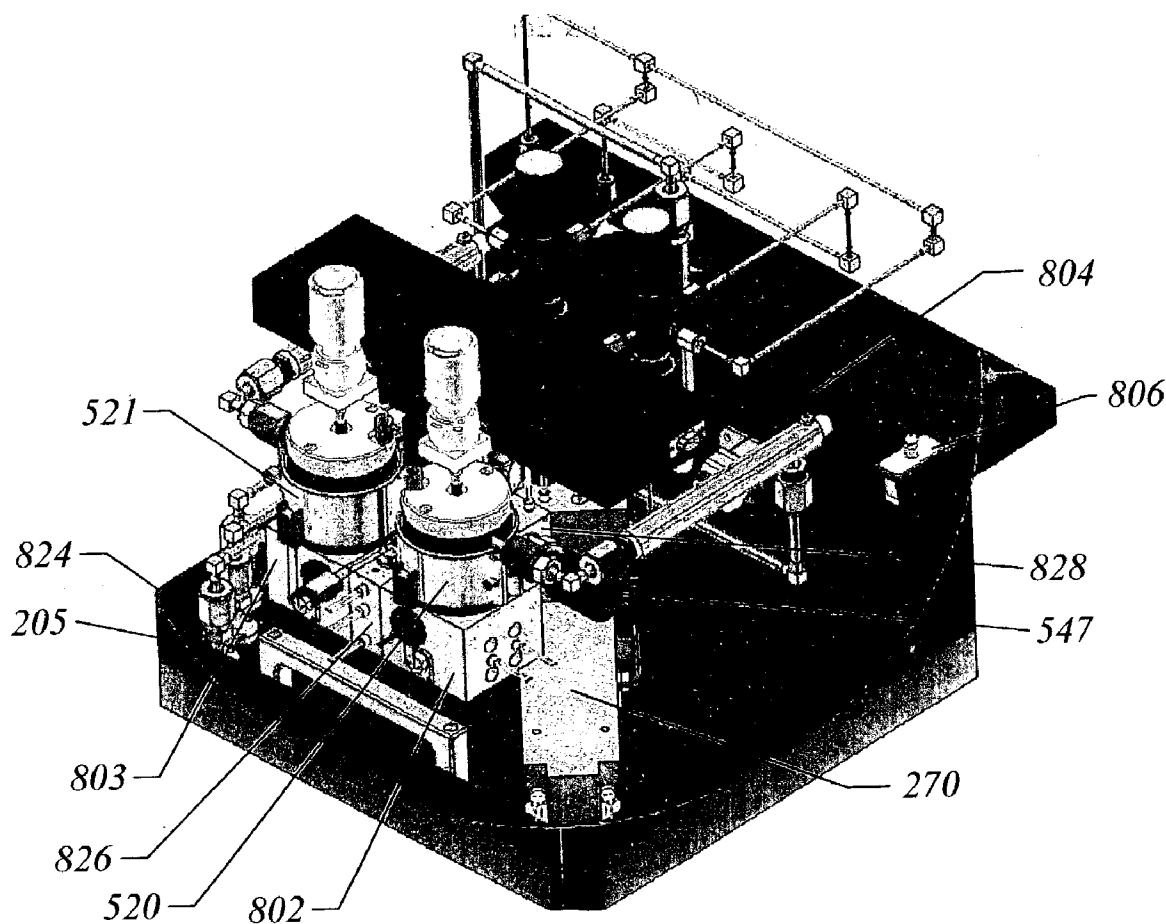


FIG. 27

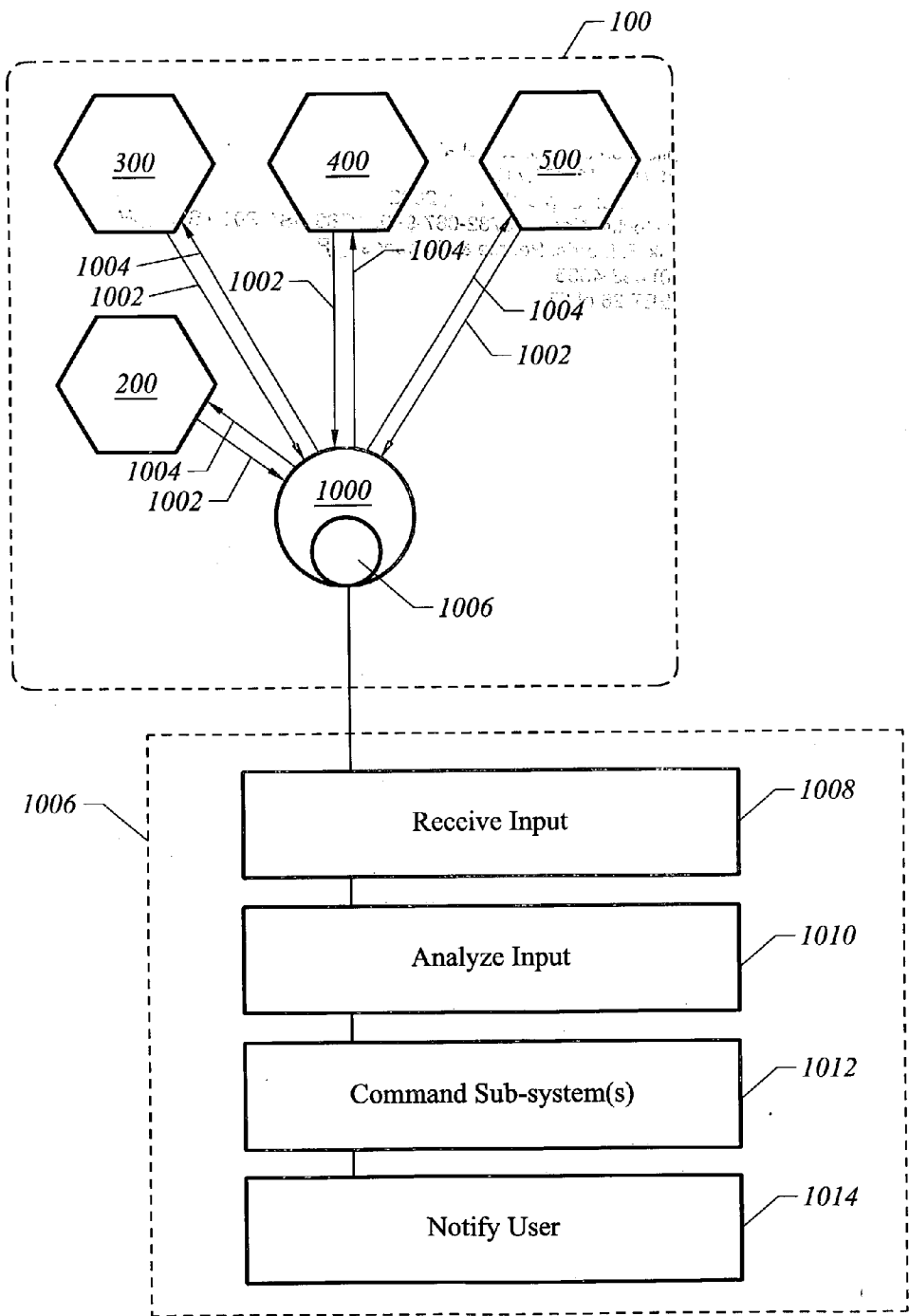


FIG. 28

APPARATUS FOR THE DEPOSITION OF HIGH DIELECTRIC CONSTANT FILMS

[0001] This application is a continuation-in-part of U.S. application Ser. No. 09/179,921 filed Oct. 27, 1998, which is incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The invention relates to an apparatus for the vaporization of liquid precursors and the controlled delivery of those precursors to form films on suitable substrates. More specifically, this invention concerns an apparatus for the deposition of a high dielectric constant film on a silicon wafer to make integrated circuits useful in the manufacture of advanced dynamic random access memory modules and other semiconductor devices.

[0004] 2. Description of the Related Art

[0005] As the dimensions of the transistors continue to decrease, the continued use of silicon dioxide as a dielectric gate material is problematic. The fundamental problem is the need to keep the capacitance of the gate high while the area of the gate is shrinking faster than the thickness of the gate dielectric stack. The capacitance C of the gate is given by $C = \epsilon_0 \epsilon_r A/d$ where A is the area of the gate, d is the thickness of the dielectric stack, k is the dielectric constant, and ϵ_0 is the permittivity of free space. To ensure higher gate oxide capacitance, the silicon dioxide layer thickness has been decreased to less than 2 nanometers and future generations may require a further reduction below 1.0 nanometer. Since the dominant transport mechanism for silicon dioxide (SiO_2) films less than approximately 3 nanometers thick is by direct tunneling of electrons or holes, the leakage current density increases exponentially with decreasing thickness. A typical leakage current density for 1.5 nanometers thick SiO_2 at 1 V is about 1 A/cm². But, as the SiO_2 thickness approaches 1 nanometer, the leakage-current density approaches an unacceptable 100 A/cm² at the same operating voltage.

[0006] Consequently, there is a need for an alternative gate dielectric material that can be used in a large enough physical thickness to reduce current leakage density and still provide a high gate capacitance. In order to achieve this, the alternative gate dielectric material must have a dielectric constant that is higher than that of silicon dioxide. Typically, the thickness of such an alternative dielectric material layer is expressed in terms of the equivalent oxide thickness (EOT). Thus, the equivalent oxide thickness (EOT) of an alternative dielectric layer in a particular capacitor is the thickness that the alternative dielectric layer would have if its dielectric constant were that of silicon dioxide.

[0007] Another consideration in selecting an alternative dielectric material is the mobility of electrons in the transistor channel. The material selected for the dielectric film effects the mobility of the carriers in the transistor channel, thereby affecting overall transistor performance. Thus, it is desirable to find an alternative dielectric material for which the mobility of carriers in the transistor channel is equivalent to or higher than that for silicon dioxide gate dielectric films. For future generation transistors, a peak mobility of 400 cm²/V.s or greater is desirable.

[0008] This drive toward smaller transistors is driven by the desire for more integrated circuits (ICs) on a semicon-

ductor die. Manufacturers are interested in replacing today's 64 megabit DRAM with memory devices in the range of 256 megabit, 1 gigabit, and higher. This need for more ICs on the same or smaller substrate footprint makes it necessary to replace conventional dielectric films, such as SiO_2 , with dielectric films having higher dielectric constants ("High k" films).

[0009] High k films are desirable because their higher dielectric constants mean they provide higher capacitance that enables closer spacing of devices without electrical interference. Such closer spacing can increase transistor density. In addition, capacitor size can be reduced because capacitors containing high dielectric constant materials, such as tantalum oxide (Ta_2O_5), usually have much larger capacitance densities than standard SiO_2 — Si_3N_4 — SiO_2 stack capacitors. In fact, tantalum oxide has a relative dielectric constant more than six times that of SiO_2 . Thus, High k materials such as tantalum oxide are becoming the materials of choice in IC fabrication.

[0010] One common method of forming a tantalum oxide film is to vaporize a liquid tantalum precursor and then deliver the tantalum vapor to a deposition chamber. FIG. 1, which is a graph of Vapor Pressure (Torr) vs. Temperature (° C.) of various compositions, graphically illustrates the large variation among the vapor pressures of tantalum precursors and other representative prior-art precursors for other semiconductor related processes. For example, at 100° C. and 1 atm TAT-DMAE has about 0.3 Torr vapor pressure while TAETO has about 0.03 Torr vapor pressure. The vapor pressures for tantalum precursors are remarkably lower than those of precursors typically used in prior art vapor delivery systems. Again referring to FIG. 1, at 100° C. and 1 atm, TEOS (Tetra Ethyl Ortho Silicate), which is commonly used in chemical vapor deposition processes to form SiO_2 films and is supplied by several prior art vapor delivery systems, has a vapor pressure of almost 100 Torr. As a result of the vast difference in vapor pressure illustrated by TAETO and TEOS, prior art vapor delivery systems do not encounter and do not provide solutions to many of the challenges resulting from the use of very low vapor pressure precursors such as TAETO and TAT-DMAE.

[0011] Prior art vapor delivery systems commonly use an integrated liquid flow controller and vaporizer without a positive liquid shut-off valve. Such a configuration, when used with low vapor pressure tantalum precursors, can lead to problems stabilizing the tantalum vapor output and difficulty achieving the constant, repeatable tantalum vapor output desired in semiconductor device fabrication. Prior art delivery systems for TEOS and other relatively high vapor pressure materials allow for the flow controller and vaporizer to be separated by a considerable distance or attach no significance to the distance between vaporizer and liquid flow meter. Positioning the vaporizer and flow meter according to prior art systems fails to adequately control precursor vapor in the case of low vapor pressure precursors.

[0012] Previous delivery systems also have cleaning systems that are intended for use with higher vapor pressure precursors whose residuals can be adequately removed ("purged") by applying low pressure or "pumping-down" the lines while flowing a gas like nitrogen that is inert, relative to these materials. Purging techniques such as these fail with tantalum systems because the residual tantalum

precursor has such a low vapor pressure that to remove it a system must introduce a solvent, such as isopropyl alcohol, ethanol, hexane, or methanol, into both the vaporization system and supply lines.

[0013] Previous vapor delivery systems avoided precursor vapor condensation by heating the delivery lines. These heating systems usually resorted to a flexible resistive heater that was wrapped around and held in direct contact with the line and then insulated. Since such systems typically operated with precursor materials having a wide temperature range within which the precursor remained vaporous, they did not need to sample the temperature of the heated line in as many locations. Typically, a single thermocouple would be used to represent the temperature of piping sections as long as four to six feet. Unfortunately, since the object of these large scale temperature control systems is to heat and monitor an average temperature of a large section of piping, these systems lack the ability to specifically control a single, smaller section of the vapor piping. An additional detriment is that these systems generally have very low efficiency when higher line temperatures are desired.

[0014] Vaporized tantalum delivery systems need to maintain the tantalum vapor above the vaporization temperature but below the decomposition temperature for a given tantalum precursor. Thus, once formed, the vaporous tantalum must be maintained at elevated temperatures between about 130° C. and 190° C. for TAT-DMAE and between about 150° C. and 220° C. for TAETO. Because of the relatively high temperatures needed and the narrow temperature band available to low vapor pressure precursors such as TAT-DMAE and TAETO, tantalum and other low vapor pressure liquid delivery systems would benefit from vapor delivery line temperature controls and methods that can achieve and efficiently provide the higher temperatures and greater temperature control needed for tantalum vapor delivery. Additionally, more precise temperature controls are needed since the usable temperature range of vaporized low pressure liquids is smaller than the usable range of prior art liquids. Because higher temperature vapor delivery is needed, tantalum delivery systems would benefit from designs that minimize the length of heated vapor delivery lines. Minimizing the length of lines requiring heating not only reduces the overall system complexity but also decreases the footprint or overall size of the system.

[0015] Current methods of tantalum oxide deposition use reaction rate limited chemical vapor deposition techniques. In reaction rate limited deposition processes, the deposition rate achieved is largely influenced by the temperature of the reaction environment. Existing chemical vapor deposition reactors do not sufficiently address the thermal losses from the substrate onto which the tantalum film is to be formed and the internal chamber components such as the gas distribution showerhead. Such thermal losses result in a non-uniform thickness of deposited tantalum and this non-uniformity is one barrier to having commercially viable tantalum oxide film formation techniques. Also, a commercially viable tantalum deposition requires a viable, in-situ cleaning process that can remove tantalum deposition formed on internal chamber components without harm to these components.

[0016] Thus, there is a need for a deposition apparatus that can deliver vaporized, measured High k precursors, such as

tantalum, hafnium, or zirconium precursors, that have been adequately mixed with process gases to a reaction chamber that provides a controlled deposition environment that overcomes the shortcomings of the previous systems.

BRIEF SUMMARY OF THE INVENTION

[0017] This invention provides an apparatus for depositing a film, particularly a High k film. To deliver High k films better, an embodiment of the apparatus has a shortened vapor delivery system in which the conduits from the vapor delivery system to the processing region are segmented into multiple individually heated and controlled sections that allow precise vapor temperature control. Additionally, an embodiment of the apparatus segments the gas and liquid delivery systems into separate but similar individually heated and controlled sections to improve vapor temperature control. Further, an embodiment of the apparatus segments the chamber assembly into individually controlled sections that are heated to allow more precise vapor temperature control, to reduce vapor deposition on the chamber itself, and to reduce chamber assembly temperature where warranted. Additionally, an embodiment of the invention allows for the simultaneous delivery of two separate High k sources, thus allowing for multi-component film deposition.

[0018] In one embodiment the apparatus includes: a chamber assembly including a chamber body and a processing region; a first vaporizer; and a vapor delivery system connecting said first vaporizer and said processing region with a first vapor path of less than approximately three feet from said first vaporizer through said vapor delivery system to said processing region.

[0019] In another embodiment the apparatus includes: a chamber assembly including a chamber body, a chamber lid, and a processing region; a first vaporizer; a vapor delivery system connecting the first vaporizer to the processing region, the vapor delivery system including: a vapor delivery manifold wherein: the vapor delivery manifold is mounted on the chamber lid; the first vaporizer is mounted on the vapor delivery manifold; and the vapor delivery manifold connects the first vaporizer to the processing region.

[0020] Yet another embodiment of the apparatus includes: a chamber assembly including a chamber body, a chamber lid, and a processing region; a first vaporizer; a vapor delivery system connecting the first vaporizer to the processing region, the vapor delivery system including: a vapor delivery manifold wherein: the vapor delivery manifold is mounted on the chamber lid; the first vaporizer is mounted on the vapor delivery manifold; and the vapor delivery manifold connects the first vaporizer to the processing region; a plurality of heated zones; a heater in thermal contact with each of the heated zones; a thermocouple in thermal contact with each of the heated zones; and a plurality of temperature controllers, wherein one of the plurality of temperature controllers is in communication with each of the heaters and thermocouples to maintain the heated zones at a first target temperature.

[0021] Another embodiment of the apparatus includes: a chamber assembly including a chamber body, a chamber lid, and a processing region; a first vaporizer; a second vaporizer; a vapor delivery system connecting the first and second vaporizers to the processing region, the vapor delivery

system including: a vapor delivery manifold wherein: the vapor delivery manifold is mounted on the chamber lid; the first and second vaporizers are mounted on the vapor delivery manifold; and the vapor delivery manifold connects the first and second vaporizers to the processing region; a plurality of heated zones; a heater in thermal contact with each of the heated zones; a thermocouple in thermal contact with each of the heated zones; and a plurality of temperature controllers, wherein one of the plurality of temperature controllers is in communication with each of the heaters and thermocouples to maintain the heated zones at a first target temperature.

[0022] An additional embodiment of the apparatus includes a double containment line for delivering a precursor to a chamber assembly, with the double containment line including: an outer tube including a first flexible section; an inner tube including a second flexible section, wherein the inner tube passes through the outer tube to create an annular space, and wherein the second flexible section is primarily within the first flexible section; a plurality of annular plugs that are positioned to enclose that portion of the annular space that lies between the first and second flexible sections to create an annular volume; and a gas, wherein the gas fills the annular volume and creates a pressure within the annular volume.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0023] The foregoing and other aspects and advantages of the present invention will be better understood from the following detailed description of preferred embodiments of the invention with reference to the drawings, in which:

[0024] FIG. 1 is a graph of vapor pressure (Torr) vs. temperature ($^{\circ}$ C.) of various compositions;

[0025] FIG. 2 is a perspective view of the processing system of the present invention;

[0026] FIG. 3 is a perspective view of four representative processing systems of the present invention mounted on a typical central wafer handling system;

[0027] FIG. 4 is an expanded plan drawing of an embodiment of a liquid delivery system (LDS) housing of the present invention;

[0028] FIG. 5 is an assembly drawing of a section of an exhaust housing wall of the liquid delivery system of FIG. 4;

[0029] FIG. 6 is a cross-sectional view of a processing chamber of the present invention;

[0030] FIG. 7 is a cross-sectional view of a lift mechanism and the lower half of a processing chamber of the present invention;

[0031] FIG. 8 is an assembly drawing of the lift mechanism of FIG. 7;

[0032] FIG. 9 is a plan view of the lid of the present invention;

[0033] FIG. 10 is a schematic of an embodiment of the chamber assembly of the present invention;

[0034] FIG. 11 is a perspective view of an embodiment of the remote plasma generator of the present invention

[0035] FIG. 12 is a perspective view of an embodiment of the exhaust system of the present invention;

[0036] FIG. 13 is a schematic view of a remote plasma generator of the present invention;

[0037] FIG. 14 is a perspective view of an embodiment of the vapor delivery system of the present invention;

[0038] FIG. 15 is a schematic drawing of a representative liquid flow controller of the present invention;

[0039] FIG. 16 is a schematic drawing of a representative liquid delivery system (LDS) and vapor delivery system with one vaporizer;

[0040] FIG. 17 is a schematic drawing of a representative LDS and vapor delivery system with two vaporizers;

[0041] FIG. 18 is an alternative embodiment of the liquid and vapor delivery systems of FIG. 2;

[0042] FIG. 19 is a schematic drawing of a second representative LDS and vapor delivery system with two vaporizers;

[0043] FIG. 20 is an alternative embodiment of the liquid and vapor delivery systems of FIG. 19;

[0044] FIG. 21 is a schematic of an embodiment of the present invention with two vaporizers mounted on the chamber lid;

[0045] FIG. 22 is a perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid;

[0046] FIG. 23 is a cross-sectional view of an embodiment of the flexible double containment line of the present invention;

[0047] FIG. 24 is a perspective view of an embodiment of the flexible double containment lines connected to and LDS housing;

[0048] FIG. 25 is a perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid with the chamber lid/vaporizer assembly in the open position;

[0049] FIG. 26 is a second perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid;

[0050] FIG. 27 is a third perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid; and

[0051] FIG. 28 is a flow chart illustrating automation of the processing system according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0052] The foregoing and other aspects and advantages will be better understood from the following detailed description of the preferred embodiments of the invention with reference to the drawings. Like reference numerals refer to corresponding parts throughout the drawings.

[0053] The present invention is directed to a novel liquid delivery system (LDS), chemical vapor deposition (CVD)

chamber, exhaust system, and remote plasma generator that together comprise a unique system especially useful for depositing thin metal-oxide films, such as hafnium silicate, as well as other films requiring vaporization of low volatility precursor liquids. This system also provides for an in-situ cleaning process that removes the metal-oxide films that are deposited on the interior surfaces of a deposition chamber as a by-product of the deposition process. The system also has application in making ultra large scale integration (ULSI) DRAM and other advanced electronic devices that require the deposition of high dielectric constant materials. In general, devices that can be made with the system of the present invention are those devices that are characterized by having one or more layers of insulating, dielectric, or electrode material on a suitable substrate such as silicon. In addition to the previously mentioned High k materials, the system of the present invention can be used to deposit silicates, aluminates, N-doped silicates, plus other metal gate electrode materials. One skilled in the art will appreciate the ability to use alternatives to the disclosed configurations and process details of the present invention without departing from the scope of the present invention. In some instances, well known semiconductor processing equipment and methodologies have not been described to avoid obscuring the present invention.

[0054] FIG. 2, which is a perspective view of the processing system of the present invention, shows the relative positions of the main components of the present invention. Processing system 100 contains a processing chamber assembly 200, a heated exhaust system 300, a remote plasma generator 400, a vapor delivery system 500, and an on-board software control system 1000 (FIG. 21). Also shown in FIG. 2 is a central substrate transfer chamber 110 representative of a cluster tool embodiment of the processing system of the present invention. Processing chamber assembly 200 comprises a lid 205 and a chamber body 210 and is attached to central transfer chamber 110. Vapors supplied via vapor delivery system 500 are provided into a processing region (not shown) within chamber assembly 200 via a heated feed-through assembly 220 that includes temperature controlled conduits formed within an inlet and mixing manifold 272 and a central mixing block 262. Cartridge heaters 264 are integrally formed into each block and, in conjunction with individual thermocouples and controllers, maintain temperature set-points within the conduits. During operation, these temperature set-points may be different for different conduits, blocks, and other chamber assembly components. For clarity, individual thermocouples and controllers have been omitted. Not visible in FIG. 2 but an aspect of the present invention is an embedded lid heater 235 (FIG. 6) integrated into chamber lid 205 beneath a heater clamping plate 234.

[0055] Processing by-products are exhausted from chamber assembly 200 via heated exhaust system 300 that is coupled to chamber assembly 200. Also shown are an isolation valve 310, a throttle valve 315, a chamber by-pass inlet 320, a cold trap 325, a cold trap isolation valve 330, and a wafer fabrication plant exhaust treatment system outlet 340 (or "foreline"). In order to provide a clearer representation of the interrelationship between and relative placement of each of the components of heated exhaust system 300, the jacket type heaters, thermocouples and controllers used to maintain set-point temperatures in exhaust port 305,

isolation valve 310, throttle valve 315, chamber by-pass inlet 320, and a by-pass line 322 have been omitted.

[0056] Activated species for cleaning are generated by remote plasma generator 400 and provided to a processing region within chamber assembly 200 via conduits within heated plasma manifold 270, and central mixing block 262. Other components of remote plasma generator 400 such as magnetron 402, auto tuner controller 410, and auto tuner 408 are visible in FIG. 2.

[0057] The main components of vapor delivery system 500 include a liquid flow meter 510 and a vaporizer 520. Three-way inlet valve 588 introduces either a precursor from precursor supply lines 508 or a solvent from solvent delivery line 591 into vapor delivery system 500. Precursor from supply line 508 enters liquid flow meter 510, which regulates the precursor liquid that flows to vaporizer 520 through vaporizer supply line 513. Heat exchanger 530 and gas heater 582 preheat carrier (or "ballast") gases and process gases respectively. Carrier gases from carrier gas source 531 enter heat exchanger 530 and are heated, before they travel via a carrier gas supply line 532 to vaporizer 520, to facilitate more complete vaporization within vaporizer 520 as well as carry vaporized liquids to chamber assembly 200. After vaporizing precursor liquid in vaporizer 520, chamber by-pass valve 545 allows the vapor to be ported either to the processing region in chamber assembly 200 via chamber outlet 550 and heated feed-through line 560, or to exhaust system 300 via an outlet 555 and heated by-pass line 322. Process gases from process gas source 579 enter gas heater 582 and are heated before they travel via a process gas supply line 586 to chamber assembly 200.

[0058] The jacket style heater, thermocouple, and controller that maintain the temperature of chamber by-pass valve 545 and heated feed-through line 560 and the jacket style heater, thermocouple, and controller that maintain the temperature of by-pass line 322 have been omitted so as not to obscure the components of vapor delivery system 500 and their relationship to chamber assembly 200 and heated exhaust system 300.

[0059] The sizes and dimensions of the various components and the placement of these components in relation to each other are determined by the size of the substrate used in the processes of the present invention. A preferred embodiment of the invention will be described herein with reference to a processing system 100 adapted to process a circular substrate, such as a silicon wafer, having a 200 mm diameter. Although described in reference to a single substrate, one of ordinary skill in the art of semiconductor processing will appreciate that the methods and various embodiments of the present invention are adaptable to the processing of multiple substrates within a single chamber assembly 200.

[0060] Turning now to FIG. 3, which is a perspective view of four representative processing systems of the present invention mounted on a typical central wafer handling system, a plurality of processing systems 100 are arranged in a cluster tool arrangement around central substrate transfer chamber 110 and supported by a mainframe 105. The Centura® mainframe system, manufactured by Applied Materials, Inc. of Santa Clara, Calif., is representative of one such cluster tool arrangement. This arrangement allows multiple chambers, shown here comprising four processing

systems **100** of the present invention, to connect to a common vacuum transfer chamber **110**.

[0061] One advantage of such an arrangement is that the central substrate transfer chamber **110** also has attached to it a loadlock or loadlocks that hold a plurality of substrates for processing in chambers attached to the central substrate transfer chamber. Although **FIG. 3** illustrates four identical processing systems **100**, another advantage of the cluster tool arrangement is the ability to place a variety of chamber types onto a single central substrate transfer chamber **110**. In such an arrangement, a substrate may move between chambers arranged around central substrate transfer chamber **110** without exposure to an air or oxygen ambient. Thus, it is a feature of the processing system **100** of the present invention that, with a variety of predetermined chamber types, a substrate could be loaded into the loadlock attached to central substrate transfer chamber **110**, sequenced through the various chambers and, as a result of the sequencing, form predetermined and desired films on a substrate processed in this manner.

[0062] It is contemplated that processing system **100**, in conjunction with other chamber types, is capable of forming complete portions of an IC. Specifically contemplated are the selections of chamber types, sequencing, and liquid delivery configurations that result in the formation of a stack capacitor having polysilicon bottom and top electrodes separated by silicon nitride and titanium nitride barrier layers that are separated by a tantalum oxide dielectric layer. Also specifically contemplated are the selections of chamber types, sequencing, and liquid delivery configurations that result in the formation of a High k transistor gate stack having an interfacial layer on the bottom interface, followed by a High k dielectric layer, followed by a post treatment, then followed by a gate electrode material. Other layers and structures are also contemplated and are intended to be included within the capabilities of the methods and apparatus described herein. It is also specifically contemplated that a single processing system **100** would alone have the processing capability of forming complete portions of an IC.

[0063] Each system **100** is shown with a cover **203** in place. Cover **203** encloses heated chamber lid **205** and temperature controlled central mixing block **262**, inlet and mixing manifold **272**, and heated plasma manifold **270** (**FIG. 2**). In one embodiment of the present invention, while chamber lid **205** is heated to operate at temperatures from 30° C. to 130° C., cover **203** is maintained at a relatively safe temperature to prevent burn injuries from contact with the heated components of lid **205**.

[0064] Remote plasma generators **400** are also shown in an alternative embodiment in which each generator is supported from the top of mainframe **105** instead of from below as shown in **FIG. 2**. So as not to obstruct the view of this alternative embodiment of remote plasma generator **400**, heated exhaust system **300** is not shown. Such a support arrangement of remote plasma generator **400** provides easier accessibility and maintenance of other components of processing system **100** as well as contributing to the reduction of the overall footprint of processing system **100**. The embodiment of the plurality of processing systems **100** of **FIG. 3** further illustrate the compact design features of the present invention. An additional aspect of compact design in this embodiment is that bulk storage containers and solvent

containers are located in an on-board LDS housing **108** on mainframe **105**. This reduces the liquid line length between containers and vaporizers allowing more precise control and repeatability of liquid delivery.

[0065] LDS housing **108** has an exhaust system that allows the user to tune the exhaust to desired flow rates at points within LDS housing **108**. Now referring to **FIG. 4**, which is a drawing of an embodiment of a liquid delivery system (LDS) housing of the present invention (viewed facing housing doors **116**), LDS housing **108** has on its left-hand side an exhaust port **107** that is attached to an exhaust line, typically house exhaust. Exhaust port **107** leads from an enclosed volume **104** created by an exhaust cover **106** and an exhaust housing wall **109**. Exhaust cover **106** is shown transparently to reveal that exhaust housing wall **109** is fitted with a number of slotted plates **111** each covering a section of exhaust housing wall **109**. LDS housing **108** has on its right-hand side a second exhaust housing wall **117** with another set of slotted plates **111**.

[0066] Now referring to **FIG. 5**, which is an assembly drawing of a section of an exhaust housing wall of the liquid delivery system of **FIG. 4**, both exhaust housing walls **109**, **117** have horizontal slots **112** and vertical slots **113** (shown as an enlarged section of housing walls **109**, **117**). Slotted plates **111** have horizontal slots **114** and bolt holes **115** (for clarity, only representative elements have been labeled in this Figure). Horizontal slots **114** on slotted plates **111** and horizontal slots **112** on housing walls **109**, **117** are the same dimensions and are spaced so that all horizontal slots **114** may align with corresponding horizontal slots **112** when a slotted plate **111** is bolted to exhaust housing wall **109** or exhaust housing wall **117**. Bolts **118** pass through bolt holes **115** and vertical slots **113** to attach slotted plate **111** to exhaust housing walls **109**, **117**. Vertical slots **113** allow each slotted plate **111** to be bolted between a raised position (at bolt position **119**) or a lowered position (at bolt position **120**) relative to exhaust housing wall **109** or **117**. When bolted using bolt positions **119** (as shown), horizontal slots **114** are fully aligned with horizontal slots **112**. When bolted using bolt positions **120**, horizontal slots **114** do not align with horizontal slots **112** at all. Fully aligning a horizontal slot **114** with a horizontal slot **112** opens a passageway **121** through the combination of slotted plate **111** and exhaust housing wall **109** or **117**. Bolting plate **111** at a position between bolt positions **119** and **120** creates a partial alignment of horizontal slots **114** and **112** and a partial opening of passageway **121**.

[0067] "Tuning" LDS housing **108** means bolting slotted plates **111** in a position that opens passageways **121** a desired amount so that air may flow across arbitrary positions within LDS housing **108** at a desired velocity, once a vacuum is applied to enclosed volume **104**. These arbitrary positions generally correspond to the locations of valves and other plumbing within LDS housing **108** that can leak noxious materials. Tuning LDS housing results in air flowing past these valves and plumbing at a velocity that would draw escaping noxious fumes into the house exhaust. For each slotted plate **111**, maximum air may flow when horizontal slots **114** are aligned with horizontal slots **112** creating passageways **121**. Conversely, minimum exhaust may flow when horizontal slots **114** are not aligned with horizontal slots **112** at all and passageways **121** are closed. Partially

aligning slots **114** and **112** partially opens passageways **121** and controls the flow through passageways **121**.

[0068] During tuning, LDS housing **108** is fitted with air velocity sensors (not shown) at the desired locations within LDS housing **108**. Exhaust port **107** is connected to house exhaust, which creates a vacuum within enclosed volume **104**. Opening passageways **121** in exhaust housing walls **109** and **117** causes air to flow through the main section of LDS housing **108** and into the exhaust. The air flow at each of the desired locations is monitored and adjusted by adjusting the air flow through the appropriate slotted plate **111**, or multiple slotted plates **111**, which could include plates on either or both of exhaust housing walls **109**, **117**. Although LDS housing **108** is shown with slotted plates **111** on opposing walls **109**, **117**, it should be understood that the invention could be practiced with the slotted plates on different walls and in differently-shaped housings.

[0069] Referring briefly to FIG. 24, one embodiment of the invention employs an LDS housing **108A** that does not have the tunable exhaust feature of LDS housing **108** (FIG. 3). In this particular embodiment of the invention, LDS housing **108A** is attached to mainframe **105** (FIG. 3) in the same manner as LDS housing **108** (FIG. 3). LDS housing **108A** is dimensioned to contain four bulk storage containers and one bulk solvent container. Precursor supply lines and solvent supply lines connect the bulk storage containers and bulk solvent container to vaporizer assemblies on any of the processing systems **100** (FIG. 3) attached to mainframe **105**. For clarity, FIG. 24 shows an example with precursor supply lines **508**, **508'** and solvent supply line **591** connecting the containers (not shown) within LDS **108A** to processing system **100**. Typically, LDS **108A** is within ten feet of the attached processing system **100**.

[0070] LDS housing **108** also has a magnetic proximity switch (not shown) that monitors whether housing doors **116** are closed, as part of an interlock system. When housing doors **116** are not closed, the interlock system de-energizes the gas and precursor supply valves. Also, as part of the interlock system, a sensor (not shown) monitors airflow through exhaust port **107** and the system de-energizes the gas and precursor control valves in the LDS housing **108** and the vaporizers should the flow be too low. These interlocks are listed in Table I, below.

[0071] FIG. 6 is a cross-sectional view of chamber assembly **200** of processing system **100** of FIG. 2. Heated chamber lid **205** is hinged to chamber body **210**. Together with O-ring **245** these form a temperature and pressure controlled environment or processing region **202** for performing deposition processes and other operations. Chamber body **210** and lid **205** are preferably made of a rigid material such as aluminum, various nickel alloys, or other materials having good thermal conductivity. O-ring **245** is formed from a chemical resistant elastomer, perfluoroelastomer, or rubber, such as Chemraz®, Kalrez®, or Viton®, respectively, or other suitable sealing material specifically designed for use in fluid seals.

[0072] When lid **205** is closed as shown in FIG. 6, a processing region **202** is formed that is bounded by a showerhead **240**, a pumping plate **208**, a pedestal heater **250**, and chamber lid **205**. Pedestal heater **250** (shown in the raised position for processing) is supported by heater shaft **256**, which extends through the bottom of chamber body

210. Heater shaft **256** is welded to pedestal heater **250** and they move as one. Imbedded within pedestal heater **250** is a resistive heater that receives power via a resistive heating element electrical connector **257**. A thermocouple in thermal contact with pedestal heater **250** senses the temperature of pedestal heater **250** and is part of a closed loop control circuit that allows precise temperature control of pedestal heater **250**. A substrate **201** is supported by the upper surface of pedestal heater **250** and is heated by the resistive heaters within pedestal heater **250** to processing temperatures of, for example, between about 400° C. and 500° C. for tantalum films formed using the methods and apparatus of the present invention. In one embodiment pedestal heater **250** is made of a ceramic material and is capable of attaining temperatures of from 200° C. to 600° C. Substrate **201** can be a substrate used in the manufacture of semiconductor products such as silicon substrates and gallium arsenide substrates and can be other substrates used for other purposes such as substrates used in the production of flat panel displays. Pedestal heater **250** and substrate **201** are parallel to showerhead **240**.

[0073] In an embodiment of the present invention, two sets of resistive heaters are imbedded within pedestal heater **250** in a manner that divides pedestal heater **250** into two heated areas. These heated areas are annular, allowing control of an outside area **297** and an inside area **294** of pedestal heater **250**. Thermocouples are arranged within inside area **294** and outside area **297** to sense the temperatures of these areas and are part of two closed loop control circuits that allow for more precise overall temperature control of pedestal heater **250**. In an embodiment of the invention, inner area **294** is heated to a percentage of outside area **297** with a single thermocouple, set in inner area **294**, used to control the temperature. One of ordinary skill will appreciate that the present invention encompasses alternative embodiments in which multiple continuous or discontinuous embedded heaters are arranged within pedestal heater **250** to provide additional heat or greater temperature control.

[0074] Processing chamber assembly **200** is coupled to central transfer chamber **110** via an opening **214**. A slit valve **215** seals processing region **202** and an enclosed volume **206** from central transfer chamber **110**. Pedestal heater **250** may also move vertically below opening **214** so that, when slit valve **215** is open, a substrate may be moved between the processing region **202** and central substrate transfer chamber **110**.

[0075] FIG. 7, which is a cross-sectional view of a lift mechanism and the lower half of a processing chamber of the present invention, and FIG. 8, which is an assembly drawing of the lift mechanism of FIG. 7, describe lift assembly **900**. Lift assembly **900** moves pedestal heater **250**, and therefore substrate **201**, into a specific position within chamber assembly **200** in relation to showerhead **240**. Lift assembly also creates an annular space **918** that allows an inert purge gas to be passed from lift assembly **900** into enclosed volume **206** to pressurize enclosed volume **206** and prevent vapor from passing from processing region **202** into enclosed volume **206**.

[0076] Briefly referring to FIG. 6, lift assembly **900** includes four lift pins **902**, which move in evenly spaced holes **281** in pedestal heater **250** about heater shaft **256** (two

lift pins are not shown for clarity). Lift pins 902 interact with a lift plate 904 that attaches to an upper carrier 910 (FIG. 7) by way of a lift tube 905. Lift plate 904 is made of aluminum with four ceramic buttons (not shown) for contacting ceramic lift pins 902. When in contact with lift plate 904, lift pins 902 slide vertically within holes 281 due to relative movement between pedestal heater 250 and lift plate 904. At some point when lowering lift plate 904 this relative movement causes lift pins 902 to retract below the surface of pedestal heater 250 and causes lift plate 904 to lose contact with lift pins 902. Pedestal heater 250 then mechanically retains lift pins 902 by means known to one of ordinary skill in the art.

[0077] Returning to FIG. 7, lift plate 904, lift tube 905, and heater shaft 256 move axially within a bellows assembly. The bellows assembly includes an upper bellows 922A and a lower bellows 922B. Heater shaft 256 is supported by a lower carrier 912. A motor 906 (FIG. 8) moves lower carrier 912 through a lead screw drive shaft 908 (FIG. 8) and a precision ground nut (not shown), which could also be a ball nut. Lower bellows 922B seals against lower carrier 912 and upper carrier 910. Upper bellows seals against upper carrier 910 and chamber mounting plate 916. This, in combination with heater shaft 256 creates an annular space 918. Annular space 918 provides a passage that conducts a purge gas from a gas inlet 920 into enclosed volume 206. Lift tube 905 is within annular space 918 and is perforated to allow the purge gas to flow between lift tube 905 and upper bellows 922A.

[0078] Now referring briefly to FIG. 8, heater shaft 256 is sealed by a heater connector 924 that is provided with gas fittings 927. A purge gas is introduced into the interior of heater shaft 256 through one of gas fittings 927 and exits through the other gas fitting 927. Nitrogen is commonly used as the purge gas, but other purge gasses are known in the art. Upper and lower carriers 910, 912, lead screw drive shaft 908, and motor 906 are supported by a lift housing 926. Lift housing 926 is attached to chamber mounting plate 916 through a heater lift leveling plate 928. Heater lift leveling plate 928 has a pivoting connection 930 to chamber mounting plate 916 and two adjustable connections 932. Adjustable connections 932 level pedestal heater 250 to shower head 240.

[0079] Returning to FIG. 7, during processing, lift pins 902 are retracted below or even with the surface of pedestal heater 250. To transfer substrate 201 out of the process chamber, lower carrier 912 lowers heater shaft 256, which in turn lowers pedestal heater 250 from the process position in relative proximity to showerhead 240 to the transfer position where the surface of pedestal heater 250 is below opening 214. As pedestal heater 250 lowers, lift pins 902 contact with lift plate 904. With continued lowering, lift pins 902 begin to protrude above the surface of pedestal heater 250. As they protrude, pins 902 lift substrate 201 off pedestal heater 250 a certain distance after which pedestal heater 250 and lift plate 904 move in unison until pedestal heater 250 is properly aligned with opening 214.

[0080] To transfer a substrate into the process chamber, the reverse occurs and lift pins 902 rise with pedestal heater 250 to lift substrate 201 off a robot blade (not shown) that has entered via opening 214. The lift mechanism pauses and the blade then retracts. Pedestal heater 250 then raises

substrate 201 to the programmed process position. During this raise, pedestal heater 250 and lift plate 904 move in tandem a certain distance, then lift plate 904 ceases moving while pedestal heater 250 continues upward. The relative motion between lift plate 904 and pedestal heater 250 causes lift pins 902 to retract within pedestal heater 250 until lift pins 902 no longer contact lift plate 904. Pedestal heater 250 continues moving until properly positioned.

[0081] The relative movement between lift plate 904 and pedestal heater 250 is determined by upper and lower carriers 910, 912. As discussed, upper carrier 910 supports lift plate 904 and lower carrier 912 supports pedestal heater 250 through heater shaft 256. Upper carrier 910 is biased by springs (not shown) within lift housing 926 to remain against a hard stop (not shown) until engaged by lower carrier 912 as the lower carrier descends. Upper carrier 910 and lower carrier 912 then travel in unison until pedestal heater 250 reaches the release position.

[0082] During the upward motion, upper carrier 910 is first pulled up by spring force and restrained by the upward motion of lower carrier 912. Upper carrier 910 stops when it contacts a hard stop (not shown). Lower carrier 912 continues to travel upward along with pedestal heater 250. This causes a relative motion between lift pins 902 and pedestal heater 250 with the lift pins receding within the support until they lose contact with lift plate 904. At the point lift pins 902 lose contact with lift plate 904, they are recessed within pedestal heater 250. The position of pedestal heater 250 is adjusted to space substrate 201 within a range of approximately 0.300" to 1.000" from showerhead 240.

[0083] In one embodiment of the invention, a chamber liner 298 is situated within chamber body 210 and dimensioned to provide a gap 299 between chamber liner 298 and chamber body 210. Gap 299 thermally isolates chamber liner 298 from chamber body 210. Chamber liner 298 remains at a higher temperature than chamber body 210 during processing because chamber body 210 is in contact with the cooler external ambient atmosphere. Consequently, less condensate forms on chamber liner 298 than on chamber body 210. Less condensate also forms on chamber body 210 since much of it is shielded from the majority of vapor within processing region 202 by chamber liner 298. Additionally, the small size of gap 299 and lack of forced flow from processing region 202 into gap 299 reduces the amount of material that diffuses through gap 299 during processing and thereby reduces the amount of condensate that may form on chamber body 210. An additional advantage of this arrangement is that chamber liner 298 may be removed for cleaning or replacement and chamber body 210 need not be cleaned as much, resulting in less wear and increasing the useful life of chamber body 210. In one embodiment of the invention, gap 299 is approximately 0.100" wide, although chamber liner 298 does occasionally come into contact with chamber body 210 to fix chamber liner 298 into position with chamber body 210.

[0084] Returning to FIG. 6, when slit valve 215 is closed and pedestal heater 250 is in the raised position for processing, processing region 202 is separated by pedestal heater 250 from enclosed volume 206. During processing, gap 207 allows material to pass into enclosed volume 206. This loss is undesirable since it reduces the efficiency of the deposition process and leads to this material condensing on cham-

ber body 210 and chamber liner 298. To prevent this, enclosed volume 206 is kept at a pressure greater than processing region 202 by introducing an inert gas such as nitrogen into enclosed volume 206 via gas inlet 920 (FIG. 7). The inert gas flows through annular space 918 (FIG. 7), enclosed volume 206, gap 207, pumping passage 223, to pumping channel 260, through chamber exhaust port 305, and is collected by the heated exhaust system 300. In one embodiment of the invention the inert gas flows from pumping channel 260 directly to isolation valve 310. Pressure transducers (not shown) monitor the pressures in enclosed volume 206 and processing region 202. Pedestal heater 250 is sometimes called a "lift" and this feature of having a greater pressure below the lift is sometimes called a "lift purge." The pressure differential from enclosed volume 206 to processing region 202 reduces material flow from processing region 202 into enclosed volume 206, reduces maintenance, and improves deposition efficiency. The pressure monitors are interlocked to de-energize the gas control valves, heaters, and chamber as listed in Table I, below.

[0085] In an embodiment of the invention, a heating channel 211 is provided within chamber body 210. A heated fluid, such as water or glycol, is passed through heating channel 211 to raise the temperature of chamber body 210. This results in less condensation on chamber body 210 with the advantages discussed above. In one embodiment, chamber body 210 is heated to operate at temperatures of from 30° C. to 105° C. using water and a Steelhead 3®, manufactured by Neslabs. The water circulated within heating channel 211 is commonly 90° C. Also, mixing block 262, manifold 272, and heated feed-through line 560 are heated to operate at temperatures of from 30° C. to 230° C., and pedestal heater 250 is heated to temperatures of between 200-600° C. In this embodiment there are sixteen independently controlled temperature zones with safety overtemperature interlocks downstream of the vaporizers.

[0086] Pumping passage 223 and pumping channel 260 are formed within chamber body 210 for removing by-products of processing operations conducted within processing region 202. Pumping channel 260 provides fluid and gas communication between components of heated exhaust system 300 and processing region 202.

[0087] Turning now to the gas delivery features of chamber assembly 200, the process gas/precursor mixture from vapor delivery system 500 and activated species from remote plasma generator 400 are delivered via temperature controlled conduits 273 and 271, respectively, to a central conduit 231 and a central lid bore-through 230 formed in lid 205. From there, gases and activated species flow through blocker plate 237 and showerhead 240 into processing region 202.

[0088] Temperature controlled conduits 271 and 273 are formed integral to heated feed-through assembly 220 comprising central mixing block 262 and inlet and mixing manifold 272. Although the embodiment represented in chamber assembly 200 of FIG. 6 indicates a heated feed-through assembly 220 comprising block 262 and manifold 272, one of ordinary skill will appreciate that the block and manifold can be combined into a single block without departing from the spirit of the present invention. A plurality of cartridge heaters 264 are disposed internally to block 262

and manifold 272 and proximally to the conduits 231, 273, 278, 265, and 276. Cartridge heaters 264 maintain a set-point in each conduit utilizing separate controllers and thermocouples for the heater of a particular conduit. For clarity, the separate thermocouples and controllers have been omitted.

[0089] Lid 205 is also provided with an annular channel 244 that circulates cooling water within that portion of lid 205 in proximity to O-ring 245. Channel 244 is connected to heating channel 211 so that the same fluid circulates through each. Channel 244 allows the majority of lid 205 to maintain the temperatures preferred for advantageous heating of showerhead 240 while protecting O-ring 245 from higher temperatures that degrade the sealing qualities of O-ring 245. This protection is desired because, when degraded, O-ring 245 is more susceptible to attack by the reactive species generated and supplied to processing region 202 by remote plasma generator 400. A flow meter (not shown) monitors the flow through channel 244 and is interlocked to de-energize the water heater and other heater controllers should the flow be too low, as listed in Table I.

[0090] Another feature of processing chamber assembly 200 of the present invention also shown in FIG. 6 is an annular resistive heater 235 embedded within chamber lid 205. This feature of chamber assembly 200 provides elevated temperatures in lid 205 in proximity to both central lid bore-through 230, showerhead 240, and the area between the lower surface of the lid 205 and showerhead upper surface 263. Formed within the top surface of lid 205 is an annular groove shaped according to the size and shape of heater 235 in order to increase surface contact and heat transfer between heater 235 and chamber lid 205. A clamping plate 234 is secured in this groove by fasteners 243 (see FIG. 9) to help increase the surface area contact between embedded heater 235 and lid 205, thereby improving the efficiency of heat transfer between heater 235 and lid 205.

[0091] Without heater 235, channel 244 could continuously remove heat from chamber lid 205. This would lower the temperature of portions of lid 205, particularly those in contact with precursor vapor, such as the area surrounding central lid bore-through 230 and the showerhead upper surface 263. While cooler lid temperatures improve conditions for O-ring 245, cooler lid temperatures could result in undesired condensation of precursor vapor. Thus, heater 235 is positioned to heat those portions of lid 205 in contact with the vaporized precursor flow. As shown in FIG. 6, for example, heater 235 is located between channel 244 and central lid bore-through 230 while also positioned to provide heating to the lid surface adjacent to blocker plate 237.

[0092] Referring now to FIG. 9, which is a top view of the lid of the present invention, the relationship of heater 235 to other components mounted on lid 205 can be better appreciated. Embedded heater 235 is indicated in phantom and is located beneath clamping plate 234 and electrical connections 236. Lid 205 also has an embedded thermocouple 204 for monitoring the temperature within lid 205 in proximity to heater 235. Thermocouple 204 is part of a feedback control circuit that monitors and controls the power supplied to heater 235 to obtain a set-point temperature within lid 205. Precise temperature control is desired in lid 205, as in all components in contact with vaporized precursor gases, to provide conditions that neither condense nor decompose low vapor pressure precursors.

[0093] For a representative 200 mm embodiment of chamber assembly 200 shown in FIG. 6, heater 235 could have a 900 W output rating and is commercially available from a variety of commercial sources such as Watlow, Inc. of Richmond, Ill. Temperature set-points between about 80° C. and 180° C. are readily obtained in lid 205 utilizing a heater rated at about 650 Watts. It will be appreciated that various heater ratings, set-points, and configurations could be utilized to obtain a wide range of temperature set-points depending upon the decomposition and condensation temperatures and other characteristics of the precursor material used. Although heater 235 is represented by a single, continuous, circular element, one of ordinary skill will appreciate that alternative embodiments wherein a plurality of continuous or discontinuous embedded heaters 235 are arranged within lid 205 to provide additional heat or greater temperature control are within the scope of the present invention.

[0094] Referring again to FIG. 6, heated lid 205 provides support for showerhead 240 and blocker plate 237. As such, showerhead 240 is attached to lid 205 via a plurality of evenly spaced fasteners 242 and blocker plate 237 is attached to lid 205 by a plurality of evenly spaced fasteners 217. Fasteners 217 and 242 are formed from a rigid material such as aluminum, varieties of nickel alloys, and other materials having good thermal conductivity. Fasteners 242 and 217 have been advantageously placed to provide clamping force to increase contact between heated lid 205 and showerhead 240 in the case of fasteners 242 and heated lid 205 and blocker plate 237 in the case of fasteners 217. Increased contact area produces greater heat transfer between heated lid 205, blocker plate 237, and showerhead 240. Increased contact area also provides a better seal against gas leaks.

[0095] Referring now to FIG. 10, which is a schematic of an embodiment of the chamber assembly of the present invention, specific aspects of the temperature controlled conduits of chamber assembly 200 of the present invention can be more fully appreciated. In particularly, one feature of the vapor delivery system of the present invention is represented by the continuous, independently temperature controlled conduits that couple the outlet of vaporizer 520 to processing region 202. Given the low vapor pressure of the tantalum and hafnium precursors, another feature of the vapor delivery system is the shortened vapor flow path from vaporizer 520 to processing region 202. Shortening the precursor vapor flow path reduces pumping losses, friction losses, and other fluid dynamic inefficiencies associated with the length of the pumping conduit as well as the inherent difficulties of pumping low vapor pressure gases. The reduction of the above fluid losses is also beneficial to the effective vaporization and delivery of low vapor pressure precursors according to the present invention because, as a result of minimizing the precursor flow path, the vapor delivery system is able to attain more stable and repeatable vapor flow rates for low vapor pressure precursors. In FIG. 10, for clarity, the schematic contains less detail regarding certain parts of the interior of the chamber assembly, more specifically from central lid bore-through to the pedestal heater 250.

[0096] Heated feed-through assembly 220, which includes inlet and mixing manifold 272 and central mixing block 262, is formed from rigid materials such as aluminum, varieties

of nickel alloys, or other materials having good thermal conductivity. The various conduits formed within heated feed-through assembly 220 couple the outlets of heated chamber feed-through 225 and process gas chamber feed-through 227 and lid bore-throughs 226 and 228 to central lid bore-through 230.

[0097] Inlet and mixing manifold 272 attaches to lid 205 forming a sealed, continuous flow path between a precursor lid bore-through 226 and precursor inlet conduit 265 and between process gas lid bore-through 228 and process gas inlet conduit 276. O-rings 216, 218, formed from a chemical resistant elastomer, perfluoroelastomer, or rubber for use in fluid seals, such as Chemraz®, or Kalrez®, or Viton® are used at lid bore-through outlets 226 and 228, respectively, to provide a seal at the mating surfaces between lid 205 and inlet and mixing manifold 272 and to seal at the mating surfaces between lid 205 and chamber body 210. Mixing conduit 278 includes the area where the process gas and precursor vapor begin to merge into a homogeneous mixture that is eventually delivered into processing region 202. The total conduit length from the beginning of mixing conduit 278 to processing region 202 is sufficiently long such that the resulting vapor/gas stream is homogeneously mixed upon arrival in central lid bore-through 230. Although the specific lengths needed to achieve homogeneous mixing will vary depending on a variety of factors such as the diameter of the conduit and gas flow rates and temperatures, a representative length from the beginning of mixing conduit 278 to central lid bore-through 230 would be about 9 inches for 0.5 inch inner diameter mixing conduit 278, mixed deposition gas conduit 273, central conduit 231, and central lid bore-through 230. In an alternative example, the length of conduit that could also result in homogeneous mixing of precursor vapor and process gases from mixing conduit 278 through mixed deposition gas conduit 273 and central conduit 231, both having inner diameters of 0.5 inches, is about 10 inches.

[0098] Inlet and mixing manifold 272 attaches to central mixing block 262 such that the outlet of gas conduit 273 is coupled to mixed deposition gas conduit 293 formed within central mixing block 262. The mating surface surrounding the outlet of gas conduit 273 and the inlet of mixed deposition gas conduit 293 is sealed with an O-ring 213 formed of a chemical resistant elastomer, perfluoroelastomer, or rubber designed for use in fluid seals, such as Kalrez®, Chemraz®, or Viton®. Similarly, the mating surface surrounding the conduit outlet of central conduit 231 and the inlet of central lid bore-through 230 is sealed with an O-ring 222.

[0099] To more clearly describe the unique temperature controlled conduits feature of heated feed-through assembly 220 of the present invention, inlet and mixing manifold 272 and central mixing block 262 are described and discussed as separate pieces. One of ordinary skill in the art, however, will appreciate that a single workpiece could be utilized having the described dimensions and characteristics of both inlet and mixing manifold 272 and central mixing block 262 without departing from the scope of the present invention.

[0100] The temperatures of each of the conduits formed internal to heated feed-through assembly 220 (265, 276, 278, 273, 293, and 231) are controlled by a plurality of independent units, each having cartridge heaters 264, ther-

thermocouples 274, and controllers 277. One unit controls the temperature of conduits 265, 276, and 278 within inlet and mixing manifold 272; another controls the temperature of conduit 273 within inlet and mixing manifold 272; and another controls the temperature of conduits 231, 293 within central mixing block 262. In each block, a plurality of cartridge (or fire-rod type) heaters 264 are advantageously arranged integral to the given block in proximity to the conduit or conduits within a given block. Multiple heaters provide the most efficient heating of the particular conduit or conduits within a given block as the heaters can be located based upon the size, shape, composition, and thermal conductivity of the particular block as well as the particular geometry of the conduits. For the representative system illustrated in FIG. 10, cartridge heaters 264 are about 0.25 inches in diameter, cylindrical in shape, have various lengths, output power capacities, and are available commercially from Watlow Inc. of Richmond, Ill. under the brand name "Fierod."

[0101] The set-point temperature is maintained within a given conduit by inputting a desired temperature set-point into the controller 277 for the particular conduit. Controller 277 could be a PID type controller similar to Model 96 that is also commercially available from Watlow, Inc. Thermocouples 274 are embedded within heated feed-through assembly 220 in proximity to each conduit such that the temperature registered by each thermocouple 274 is approximately the same as the temperature within the controlled gas conduit. The position of thermocouple 274 relative to a given gas conduit varies depending upon a number of factors such as the thermal conductivity of the material used to fabricate the given block and the type of thermocouple 274 used. The signal from thermocouple 274 is sent to controller 277, which compares the temperature from thermocouple 274 to the input temperature set-point. Based on the result of this comparison, controller 277 will either increase, decrease, or maintain power supplied to cartridge heaters 264. One advantage of utilizing a plurality of independent thermocouples 274 is that the specific conditions of a given conduit block are taken into account depending upon its geometry, heat losses, and location relative to other sources of heat.

[0102] For example, inlet and mixing manifold 272 is in direct contact with heated lid 205. Unless the temperatures between manifold 272 and lid 205 exactly match, manifold 272 will either gain energy from or lose energy to lid 205. The effect of heat transfer between lid 205 and inlet and mixing manifold 272 on the temperature of conduits 265, 276, and 278 within manifold 272 will be reflected in the temperature detected by a thermocouple 274 located within manifold 272. As a result, the controller 277 associated with manifold 272 can increase or decrease the power output of cartridge heaters 264 embedded within manifold 272 in proximity to conduits 265, 276, and 278 to compensate for heat transfer between manifold 272 and lid 205. In the same way, energy transfer between central mixing block 262 and lid 205 is compensated for by the thermocouple, heater, and controller unit associated with block 262. An additional advantage of independently controlling separate areas is that these areas can be heated to different temperatures.

[0103] Heat losses from conduit 273 are different from heat transfer in other conduits within manifold 272 and block 262. Gas conduit 273 has a higher potential for heat

loss because that part of mixing manifold 272 is not in direct contact with heated lid 205 and has a larger surface area that is exposed to the ambient conditions (about 25 degrees Celsius within the wafer fabrication facility) when cover 203 is removed. When cover 203 is in place, however, as illustrated in FIG. 2, temperatures surrounding heated feed-through assembly 220 increase to about 70 to 80 degrees Celsius. Thus, the heater, thermocouple, and controller unit dedicated to gas conduit 273 are utilized to compensate for the heat transfer characteristics peculiar to that conduit.

[0104] More generally, an aspect of the present invention is an apparatus to provide a pre-determined temperature within a conduit by the selection, placement, and use of a controller, heater, and thermocouple control unit that utilize the apparatus described above. Another feature of the multiple, independent cartridge heater, thermocouple, and controller units of the present invention is that a uniform conduit temperature throughout heated feed-through assembly 220 can be achieved. Because of their independence, each controller is able to efficiently maintain set-points irrespective of conditions in surrounding blocks, while taking into account: the specific heat losses and conditions surrounding each block, the specific outer shapes of each block, and the geometry of the conduits formed within each block.

[0105] In another aspect of the present invention, the temperature set-point of each conduit could be set and maintained to induce a negative temperature gradient where the set-point temperature of central conduit 231 is less than the set-point of conduit 273 and the temperature of conduit 273 is less than that of conduit 278. Alternatively, a positive temperature gradient could be induced where the temperature increases from conduit 278 to conduit 273 to central conduit 231.

[0106] In a specific embodiment of the apparatus of chamber assembly 200 of the present invention, mixing manifold 272 is aluminum with the following dimensions: about 7 inches long, about 3.2 inches wide, and about 3.2 inches high. A representative cartridge heater 264 for this block is cylindrically shaped, 0.375 inches in diameter, and 7.0 inches long with a total power output capacity of 500 Watts. In an embodiment of the method and apparatus of the present invention, a single cartridge heater 264 or a plurality of heaters 264 of a selected total power output capacity of about 500 Watts is employed about conduit 273 so that the temperature within mixed deposition gas conduit 273 remains above the vaporization temperature and below the decomposition temperature of the carrier gas/precursor vapor/process gas mixture flowing within conduit 273.

[0107] In a specific embodiment where gas conduit 273 is as described above, a thermocouple 274 could be placed between about 0.125 inches to 0.5 inches away from mixed deposition gas conduit 273. In an embodiment of the present invention where the carrier gas/precursor vapor/process gas mixture within conduit 273 comprises a hafnium precursor, a process gas such as oxygen, and a carrier gas such as nitrogen, conduit 273 temperatures between about 130° C. and 160° C. would prevent both condensation and decomposition of the hafnium/oxygen/nitrogen mixture.

[0108] A further aspect of the temperature controlled conduits of chamber assembly 200 of the present invention provides temperature controlled delivery of vaporized precursor from vaporizer 520 to central lid bore-through 230.

Vaporized precursor exits vaporizer **520** via vaporizer outlet **540** and enters vaporizer outlet manifold **542** that is coupled to vapor inlet **544** of chamber by-pass valve **545**. When by-pass valve **545** is positioned to direct flow to processing region **202**, precursor vapor exits by-pass valve **545** via chamber outlet **550** flowing then to heated feed-through line **560** that is coupled to heated precursor feed-through **225**. In an embodiment of the invention heated feed-through line **560** and heated precursor feed-through **225** are one part. A jacket type temperature controller controls the temperature in conduit **290** between the inlet **544** of three-way valve **545** and the inlet to heated precursor feed-through **225**, encompassing line **560** and by-pass valve **545**. The jacket type temperature controller comprises a jacket or wrap style heater **275**, a controller **277**, and a thermocouple **274** and is utilized to maintain a temperature set-point in line **560** and valve **545**. The temperature in manifold **542** is controlled by a separate jacket type temperature controller. From a temperature-controlled precursor feed-through conduit **225**, precursor vapor flows through precursor lid bore-through **226** into precursor inlet conduit **265** of inlet and mixing manifold **272**. An airtight seal is maintained between precursor feed-through conduit **225** and precursor lid bore-through **226**, and between process gas chamber feed-through **227** and process gas bore-through **228** using O-rings and a correct fit of chamber lid **205** to chamber body **210**. From precursor inlet **265**, the precursor vapor flows into mixing conduit **278** where it mixes with process and carrier gases supplied via process inlet conduit **276**.

[0109] The temperature of precursor vapor within precursor feed-through conduit **225** is maintained by a temperature controlled chamber feed-through **219**, which includes a plurality of cartridge heaters **264**, a thermocouple **274**, and a controller **277**. Another feature of temperature controlled chamber feed-through **219** is thermal choke or air gap **212**. Air gap **212** is annular about precursor feed-through conduit **225**, cartridge heaters **264**, and thermocouple **274** and insulates the components of temperature-controlled chamber feed-through **219** from the thermal influences of chamber body **210**. Thus, by utilizing the plurality of heaters, controllers and thermocouples described above and the features of heated lid **205**, chamber assembly **200**, and vapor delivery system **500**, the invention provides a temperature controlled flow path for vaporized low vapor pressure precursors from vaporizer **520** to processing region **202**.

[0110] Process gas heater **582** provides temperature control for process gas and carrier gases for use in chamber assembly **200**. Process gas heater **582** is located proximally to chamber body **210** and, more specifically, to process gas chamber feed-through **227** such that the gas temperature exiting gas heater **582** is approximately the same as the gas temperature entering process gas chamber feed-through **227**. From process gas chamber feed-through **227**, temperature controlled process and carrier gases pass through process gas lid bore-through **228** and enter process gas inlet **276** of inlet and mixing manifold **272**.

[0111] Another aspect of the present invention is the use of process gas heater **582** to heat process gas and carrier gases above the temperature of the vaporized precursor gas stream. This virtually eliminates the risk that the vaporized precursor will condense when the heated process gas stream and the vaporized precursor gas stream intersect and mix within mixing conduit **278**. For example, the temperature set-point

of process gas heater **582** could be about 5-10° C. above the temperature set-point of vaporizer **520**. Alternatively, a set-point could be utilized that results in process gas temperatures at least as high as the merging precursor vapor stream. In much the same way, to prevent precursor decomposition, the temperature of process gas and carrier gas can be controlled to remain below a set-point where decomposition would occur upon mixing with the precursor vapor stream.

[0112] Another aspect of the independent temperature controlled conduits of chamber assembly **200** is that temperature changes within a specific conduit associated with the volume expansion can be compensated for by the independent heater, controller and thermocouple of that particular conduit. For example, heated feed-through line **560** and vaporizer outlet manifold **542** are heated by separate thermocouples, controllers, and jacket style heaters (not shown) so that temperatures within heated feed-through line **560** and vaporizer outlet manifold **542** can be individually maintained above the condensation temperature and below the decomposition temperature of the vaporized precursor, or between about 100° C. and 190° C.

[0113] The independently temperature-controlled conduits feature of the present invention provides for a more precise temperature control than previously available and this allows for delivery of vaporized liquid under a variety of thermal conditions that exist as a result of the different environments to which each conduit is exposed. Utilizing the independent thermocouple, controller, heater units that are part of processing system **200** and vapor delivery system **500**, a series of temperature controlled conduits is provided that can deliver vaporized low vapor pressure precursors from the outlet of vaporizer **520** to processing region **202**. For example, each temperature controlled conduit could be set to maintain a set-point 2-3 ° C. hotter than the previous conduit so that a slightly positive thermal gradient is maintained between the vaporizer **520** and outlet of central conduit **231** into processing region **202** or, more generally, an overall change in temperature could be maintained between the vaporizer outlet temperature and the temperature in central conduit **231**, or a change in temperature of about 20-25° C.

[0114] Although the heater type is specified in describing conduit temperature control (such as with cartridge heater temperature controlled conduit **293** and jacket heater temperature controlled conduit **279**) these descriptions are not intended to be limiting. One of ordinary skill in the art will appreciate that a variety of heater types, thermocouples, and controllers can be utilized without departing from the scope of the present invention.

[0115] There is another aspect to the thermally controlled conduits of processing chamber assembly **200** and vapor delivery system **500** of the present invention. The conduits used downstream of vaporizer **520** in the precursor flow path, as shown in FIG. 10 between vaporizer **520** and central lid bore-through **230**, have progressively larger diameters that result in increasing cross-sectional flow areas resulting in an expanded gas flow volume within these conduits. The volume expansion and corresponding pressure drop within the precursor delivery conduits further help maintain conduit conditions that neither condense nor decompose the vaporized precursor. These conditions are above the vapor con-

densation temperature, yet below its decomposition temperature for the pressure within the vapor supply conduits. For example, representative inner diameters for the chamber illustrated in FIG. 10, are a vaporizer outlet manifold 542 with an inner diameter of 0.18 inches, a heated feed-through line 560, chamber feed-through 225, and inlet 265 with inner diameters of 0.40 inches and a mixed deposition gas conduit 278 and central conduit 231 with inner diameters of about 0.5 inches. For another example, the cross-sectional area of conduit 273 downstream of the intersection of the precursor gas flow and the process gas flow is larger than the sum of the merging gas flows.

[0116] The increased volume and correspondingly decreased pressure achieved by advantageously selecting the diameter of manifolds, conduits, and lines, such as 542, 560, 225, 226, 265, 278, 273, 293, and 231 (all downstream from vaporizer 520) in conjunction with the temperature control provided by the thermocouple, heater, and controller sets described above provide a controlled temperature and pressure regime between vaporizer 520 and processing region 202 such that very low vapor pressure precursors, dopants, or other processing materials, may be delivered to processing area 202 without undesired condensation or decomposition.

[0117] Referring now to FIG. 11, which is a perspective view of an embodiment of the remote plasma generator of the present invention, another aspect of the processing system 100 of the present invention is a remote plasma generator 400, chamber assembly 200, and components of heated exhaust system 300. Remote plasma generator 400 creates a plasma outside of or remote to processing region 202 for cleaning, deposition, annealing, or other processes within processing region 202. One advantage of remote plasma generator 400 is that the generated plasma or activated species created by remote plasma generator 400 may be used for cleaning or process applications within the processing region without subjecting internal chamber components such as pedestal heater 250 or showerhead 240 to the plasma attack that usually results when conventional RF energy is applied within process region 202 to create a plasma. Several components of remote plasma generator 400 are visible, such as magnetron 402, auto tuner controller 410, isolator 404, auto tuner 408, applicator cavity 416, and applicator heat insulation disc 424.

[0118] Magnetron assembly 402 houses a magnetron tube, which produces microwave energy. The magnetron tube comprises a hot filament cylindrical cathode surrounded by an anode with a vane array. This anode/cathode assembly produces a strong magnetic field when it is supplied with DC power from a power supply. Electrons in this magnetic field follow a circular path as they travel between the anode and the cathode. This circular motion induces voltage resonance, or microwaves, between the anode vanes. An antenna channels the microwaves from magnetron 402 to isolator 404 and wave guide 406. Isolator 404 absorbs and dissipates reflected power to prevent damage to magnetron 402. Wave guide 406 channels microwaves from isolator 404 into auto tuner 408. Auto tuner 408 compensates for differences between the impedance of magnetron 402 and the impedance of microwave applicator cavity 416 to achieve the minimum degree of reflected power by adjusting the vertical position of three tuning stubs located inside auto tuner 408. Auto tuner 408 also supplies a feedback signal to the

magnetron power supply to continuously adjust the actual forward power to the set-point. Auto tuner controller 410 controls the position of the tuning stubs within auto tuner 408 to minimize reflected power. Auto tuner controller 410 also displays the position of the stubs as well as forward and reflected power readings.

[0119] Microwave applicator cavity 416 ionizes a gas or gases supplied via gas supply inlet 412. Gas supplied via gas supply inlet 412 enters a water cooled quartz or sapphire tube within microwave applicator cavity 416, is subjected to microwaves and ionizes. This produces activated species that can be used in cleaning and processing operations within processing region 202. One such cleaning gas is NF_3 that can be used to supply activated fluorine for cleaning processing region 202. Activated species can also be used to anneal or otherwise process semiconductor or other materials present on a substrate 201 positioned within processing region 202. An optical plasma sensor 414 detects the existence of plasma within cavity 416. Activated species generated within cavity 416 are supplied to activated species chamber feed-through 229 via adapter tube 418. Adapter tube 418 is insulated from the elevated temperature of chamber body 210 by adapter tube heat insulation disc 424. In an embodiment of the invention, adapter tube 418 is eliminated and activated species are supplied directly to activated species chamber feed through from cavity 416.

[0120] From activated species chamber feed-through 229, the activated species pass through lid bore-through 221 and enter heated plasma manifold 270 that provides an O-ring sealed, air tight conduit (activated species conduit 271) between lid bore-through 221, and central gas feed-through 231 within central mixing block 262. In an embodiment of the invention, the remote plasma generator uses RF energy, rather than microwave.

[0121] Referring FIG. 12, which is a perspective view of an embodiment of the exhaust system of the present invention, the components and features of heated exhaust system 300 of processing system 100 can be better appreciated. The components of heated exhaust system 300 are collectively referred to as a foreline. The foreline is in communication with a vacuum pump (not shown) and wafer fabrication facility exhaust systems (not shown) to provide for reduced pressure processing operations within processing region 202. Exhaust from processing and cleaning operations conducted within processing region 202 is exhausted via chamber exhaust port 305. In this embodiment of the invention, exhaust port 305 (FIG. 2) is eliminated and the exhaust processing region 202 is exhausted directly into isolation valve 310. When closed, isolation valve 310 shuts off chamber assembly 200 from down stream vacuum pump systems. During normal operation, isolation valve 310 is open and throttle valve 315 opens and closes to regulate pressure within processing region 202. By-pass inlet 320 (FIG. 2) receives precursor vapor/carrier gas mixture from chamber by-pass valve outlet 555 (FIG. 10) when chamber by-pass valve 545 (FIG. 2) is positioned to flow precursor vapor/carrier gas mixture to temperature controlled by-pass line 322 (FIG. 2). Exhaust system components (chamber exhaust port 305, isolation valve 310, throttle valve 315, by-pass inlet 320, and by-pass line 322) are temperature controlled to prevent unreacted precursor condensation. Cold trap 325 and the remaining downstream exhaust system components are maintained at or below room tempera-

ture. In an embodiment of the invention, the temperatures of the cold trap **325** and the remaining downstream exhaust system components are not maintained at a specific temperature.

[0122] As a result, any unreacted vapor remaining in the exhaust stream from processing region **202**, or vapor from chamber by-pass valve **545** will remain gaseous in the temperature controlled or heated portion of exhaust system **300** and then condense within cold trap **325** thus preventing damage to the vacuum pumps or accumulation and resulting line blockages within exhaust system piping. Additionally, collection of unreacted vapor within cold trap **325** also minimizes the exposure of maintenance personnel to potentially hazardous chemicals. Cold trap **325** is equipped with an isolation valve **330** for separating cold trap **325** from vacuum pumping systems to allow for routine maintenance or cleaning.

[0123] To provide a clear illustration of the relationships between the various components of exhaust system **300** and the other components of processing system **100**, the independent thermocouple, controller, and heater utilized as part of the temperature controlled feature of exhaust system **300** is not shown in FIG. 12. Turning briefly to FIG. 16, which is a schematic drawing of a representative liquid delivery system (LDS) and vapor delivery system with one vaporizer, the temperature controlled conduits of exhaust system **300** appear more clearly. A jacket style heater **275**, thermocouple (not shown), and controller (not shown) are utilized to measure and maintain a set-point temperature in chamber exhaust port **305**, isolation valve **310**, throttle valve **315**, and chamber bypass inlet **320**, thereby combining to create a jacket heater controlled conduit **292** in the exhaust components upstream of cold trap **325**. Chamber by-pass line **322** is included in another jacket style heater temperature controlled conduit **291** between chamber by-pass valve **545** and exhaust by-pass inlet **320** using a separate thermocouple, controller, and heater **275**.

[0124] Turning now to FIG. 14, which is a perspective view of an embodiment of the vapor delivery system of the present invention, the compact design feature of vapor delivery system **500** of the present invention can be better appreciated. Vapor delivery system **500** provides a method and an apparatus for supplying controlled, repeatable, vaporization of low vapor pressure precursors for film deposition on a substrate **201** located within processing region **202**. One method provides for the direct injection of vaporized High k precursors. One of ordinary skill will appreciate the specific features detailed below that allow vapor delivery system **500** to vaporize and precisely control the delivery of liquid precursors including those precursors having vapor pressures significantly lower than precursors utilized in prior art vapor delivery systems or, specifically, precursors having vapor pressures below about 10 Torr at 100° C. (FIG. 1).

[0125] The various components of vapor delivery system **500** are placed in close proximity to chamber assembly **200** in order to minimize the length of temperature controlled vapor passageways between the outlet of vaporizer **520** and processing region **202**. Even though practice in the semiconductor processing arts is to place vapor systems remotely from processing chambers to either ensure serviceability or reduce the amount of cleanroom space occupied by a processing system, vapor delivery system **500** of the present

invention utilizes an innovative compact design that allows all system components—except for the bulk liquid precursor, carrier gas, and process gas supplies—to be located directly adjacent to chamber assembly **200** and in close proximity to precursor and process gas chamber feed-throughs **225** and **227**.

[0126] A low vapor pressure liquid precursor can be stored in a bulk storage container (ampoule) **503** located remotely or on mainframe support **105** in LDS housing **108** (FIG. 3) in closer proximity to processing chamber assembly **200**. Locating bulk storage containers and solvent containers in on-board LDS housing **108** on mainframe **105** reduces the liquid line length between containers and vaporizers allowing more precise control and repeatability of liquid delivery. Liquid precursor stored in container **503** is maintained under pressure of an inert gas such as Helium at about 15 to 60 psig supplied by supply line **507** (FIGS. 16 and 17). The gas pressure within container **503** provides sufficient pressure on the liquid precursor such that liquid precursor flows to other vapor delivery system components, thus removing the need for a pump to deliver the liquid precursor. The outlet of container **503** is provided with a shut-off valve (not shown) to isolate bulk storage container **503** for maintenance or replenishment of the liquid precursor. As a result of the pressure head on container **503**, liquid precursor from container **503** is provided to a precursor supply line **508** and the precursor inlet **509** of three-way inlet valve **588**. When valve **588** is set to pass through liquid precursor, three-way inlet valve **588** provides liquid precursor to precursor/solvent outlet **594** and into precursor/solvent supply line **592** to liquid flow meter inlet **505**. Liquid flow meter **510** measures precursor flow rate and provides liquid precursor via liquid flow meter outlet **511** (FIGS. 15, 16, and 17) to vaporizer supply line **513** and then to vaporizer inlet **515**. Vaporizer **520** in conjunction with a heated carrier gas (described below) converts the liquid precursor into precursor vapor.

[0127] Carrier gas supply line **525** supplies a carrier gas, such as nitrogen or helium, to carrier gas heat exchanger **530** at a pressure of about 50 Torr. Carrier gas heat exchanger **530** preheats the carrier gas to a temperature such that the heated carrier gas stream entering vaporizer **520** does not interfere with the efficient vaporization of the precursor liquid undergoing vaporization within vaporizer **520**. Carrier gas heat exchanger **530** heats the gas using a resistive heater like the carrier gas heat exchanger Model HX-01 commercially available from Lintec. Heated carrier gas is provided to vaporizer **520** via carrier gas supply line **532** and carrier gas inlet **535**. The heated carrier gas should not be overheated because a carrier gas heated above the decomposition temperature of the precursor undergoing vaporization could result in precursor decomposition within vaporizer **520**. Thus, carrier gas heat exchanger **530** heats the carrier gas into a temperature range bounded by the condensation temperature of the precursor at the lower limit and the decomposition temperature of the precursor at the upper limit.

[0128] For a hafnium precursor a representative vaporization temperature is about 130° C. and a decomposition temperature is about 190° C. A typical carrier gas such as nitrogen is provided to a vaporizer **520** that is vaporizing a hafnium precursor at about between 200 and 2000 standard cubic centimeters per minute (scm) and a temperature of between about 110° C. and about 160° C. These conditions

result in a vaporized precursor flow rate in the range of about 10-50 milligrams per minute. In an embodiment of the invention the vaporization temperature can be set up to 180° C.

[0129] Carrier gas temperature should also be such that the temperature of the carrier gas entering vaporizer 520 is at least as high if not higher than the vaporization temperature of the precursor being vaporized in vaporizer 520. Of particular concern is the prevention of precursor vapor condensation within the small diameter conduits that exist within vaporizer 520. Carrier gas temperatures below vaporization conditions within vaporizer 520 could cool the vaporized precursor enough that condensation results and should therefore be avoided.

[0130] Referring now to FIG. 15, which is a schematic drawing of a representative liquid flow controller of the present invention, liquid flow controller 528 includes a liquid flow meter 510 and a vaporizer 520. Liquid precursor enters liquid flow meter 510, which generates a measured flow rate signal 512. The precursor flows from liquid flow meter outlet 511 into vaporizer supply line 513 and then into vaporizer inlet 515. Located within vaporizer 520 between vaporizer inlet 515 and metering valve 524, is a positive shut-off valve 522 that provides the capability to cut-off liquid flow before the vaporization point within vaporizer 520. Vaporizer 520 reads signal 512 and adjusts metering valve 524 to achieve a target flow. Positive shut off valve 522 is a pneumatic valve that is controlled by on-board software control module 1000 (FIG. 21). Although metering valve 524 can provide a shut-off capability when in a "closed" or zero set-point condition, positive shut-off valve 522 provides added assurance that no liquid will continue to flow through vaporizer 520 when liquid flow controller 528 is in a "closed" or zero set-point condition. The location of positive shut-off valve 522 relative to metering valve 524 is such that there is a minimal volume of liquid that could remain in the line between shut-off valve 522 and metering valve 524.

[0131] A typical flow rate signal 512 is measured in milligrams per minute or mg/min. A representative flow rate for a High k precursor is 7 mg/min for a representative HfO₂ film produced utilizing the method and apparatus of the present invention.

[0132] A representative vaporizer 520 suitable for vaporization of low vapor pressure liquids could position positive shut-off valve 522 about one inch or less from metering valve 524. For example, using a 0.125 inch outer diameter line between shut-off valve 522 and metering valve 524 creates a liquid precursor volume of about 0.012 cubic inches. Reducing the volume between these components minimizes the amount of precursor that could vaporize after positive shut-off valve 522 is closed. Positive shut-off valve 522 could also be a type of valve known as a "zero dead volume" valve.

[0133] Another aspect of liquid flow controller 528 is that the length of vaporizer supply line 513, which is typically 0.069 inch inner diameter stainless steel piping is minimized to attain controllable low vapor pressure precursor output from vaporizer 520. Minimizing the length of supply line 513 allows more effective liquid metering and control by minimizing the distance between the liquid flow meter outlet 511 and vaporizer inlet 515. Spacing between vaporizer inlet

515 and liquid flow meter outlet 511 of about 3.4 inches or between about 2 inches and 15 inches leads to more effective metering and controlled vaporization of low vapor pressure precursors, for example liquid precursors having a vapor pressure below about 10 Torr at 100° C.

[0134] In an embodiment of the invention, liquid flow meter 510 contains the metering valve 524 and vaporizer 520 does not. In this embodiment liquid flow meter 510 measures the flow and also adjusts the flow using the self-contained metering valve 524. As a result, there is no flow rate signal 512 between vaporizer 520 and liquid flow meter 510, vaporizer 520 vaporizes the flow, but vaporizer 520 does not perform a metering function.

[0135] Minimizing the distance between liquid flow meter 510 and vaporizer 520, however, adds to the number of vapor delivery system components placed in proximity to chamber assembly 200 and increases the density of equipment mounted on chamber assembly 200. But vapor delivery system 500, along with the remote plasma generator 400, and heated exhaust system 300, have been designed to minimize interference between the subsystems of processing system 100 while achieving the compact design desired in cluster tool wafer processing systems.

[0136] Returning to FIG. 14, vaporized precursor flows from vaporizer outlet 540, into vaporizer outlet manifold 542, then into vapor inlet 544 of temperature controlled by-pass valve 545. When valve 545 is set to pass vaporized precursor to the chamber, by-pass valve 545 supplies vapor to chamber outlet 550 and then into temperature controlled heated feed-through line 560. The thermocouples, controllers, and jacket style heaters that maintain a temperature set-point within vaporizer outlet manifold 542, chamber by-pass valve 545, and heated feed-through line 560 are a feature of the vapor delivery system 500, but are omitted for clarity. The internal piping of chamber by-pass valve 545 allows the vaporized precursor/heated carrier gas mixture to be sent to processing region 202 via chamber outlet 550.

[0137] Additionally or alternatively, while stabilizing vapor flow or conducting cleaning operations within processing region 202, chamber by-pass valve 545 could direct the vaporized precursor/heated carrier gas mixture to heated by-pass line 322 (FIG. 2) of heated exhaust system 300 (described above) via outlet 555. One advantage of chamber by-pass valve 545 of the present invention is that once liquid flow controller 528 attains a desired set-point vapor flow rate the vaporized precursor/heated carrier gas mixture can either be directed to the chamber for deposition or to the foreline by-pass inlet 320 for disposal. Thus, independently from any operations within processing region 202, liquid flow controller 528 continues to produce a stable, consistent vapor flow rate. And chamber by-pass valve 545 used in conjunction with liquid flow controller 528 provides repeatable, stable vapor flow rates to consecutive substrates 201 within processing region 202. Such repeatable, stable vapor flow rates are desired for the deposition of transition metal dielectric materials such as tantalum oxide for used in ICs in devices such as stacked capacitors and hafnium oxide for use in ICs in devices such as High k transistors.

[0138] Vaporizer outlet manifold 542 and heated feed-through line 560 are standard piping that could be made of stainless steel. Heated feed-through line 560 should be as short as possible to minimize the length of travel of vapor-

ized precursor within the system to between about 4 to 6 inches. Heated feed-through line **560** is in communication with chamber outlet **550** and precursor chamber heated feed-through **225**.

[0139] To prevent condensation of the vaporized precursor within the vaporized precursor/heated carrier gas mixture, heated feed-through line **560** and vaporizer outlet manifold **542**, like all precursor supply conduits downstream of vaporizer **520**, have an inner diameter that is greater than the inner diameter of the liquid supply line into vaporizer **520**. As discussed previously regarding FIG. 15, the vaporizer liquid supply line is typically made of stainless steel with about a 0.069 inch inner diameter while the conduits downstream of vaporizer **520** could have a larger diameter, such as an outer diameter of about 0.5 inches, or an inside diameter of about 0.4 inches.

[0140] Vapor delivery system **500** also has a temperature controlled process gas feature. Process gas heater **582**, which is similar to carrier gas heat exchanger **530** described above, receives process gas via supply line **580** from a process gas supply. Suitable process gases depend on the desired film deposition. Typically, oxygen (O_2) and nitrous oxide (N_2O) are suitable for oxidation processes and ammonia (NH_3) is suitable for nitride processes. Additionally, nitrogen (N_2) could be added to the process gas flow as a carrier gas. The term process gas stream used below refers to all gas flows out of gas heater **582** and is intended to include process gas, carrier gases, or other gases described above.

[0141] Process gases and carrier gases are preheated by process gas heater **582** so that the resulting process gas stream is maintained above the temperature of the adjacent vaporized precursor gas stream. Maintaining the process gas stream temperature about 10° – 15° °C. above the temperature of the vaporized precursor gas stream assists in the prevention of inadvertent condensation of the precursor vapor when the gas streams intersect and begin to mix within mixing conduit **278**. Similarly, gas heater **582** also helps ensure that process gas stream temperatures are maintained below the decomposition temperature of the precursor gas stream so that inadvertent decomposition of the precursor vapor stream does not occur when the gas streams mix within mixing conduit **278**.

[0142] Thus, a temperature controlled gas stream exits process gas heater **582** via outlet **584** and enters process gas supply line **586**. Returning briefly to FIG. 10, from process gas supply line **586** the process gas stream flows through process gas chamber feed-through **227** that in turn flows into heated process gas inlet conduit **276**. Process gas inlet conduit **276** flows into and mixes with vaporized precursor flow stream in heated mixing conduit **278**.

[0143] Referring again to FIG. 14, another feature of vapor delivery system **500** is the ability to provide a solvent flush capability to those conduits that come into contact with the vaporized low vapor pressure precursors. Such solvent operations complement the ability of the method and apparatus of the present invention to vaporize low vapor pressure liquids with the ability to clean the apparatus afterwards. A solvent such as anhydrous isopropyl alcohol, methanol, hexane, ethanol, or other suitable solvent is supplied from a bulk solvent container **589** into precursor/solvent three-way valve **588** via solvent delivery line **591** and inlet **590**. From

three-way valve **588** the solvent follows the same flow path as a vaporized precursor through the various components of vapor delivery system **500** and, depending upon the alignment of chamber by-pass valve **545**, to chamber assembly **200** or exhaust system **300** via by-pass line **322**. As the solvent flows through the various conduits that are exposed to liquid precursor, such as the conduits of liquid flow controller **528**, the solvent mixes with precursor liquid and purges the line of residual precursor. This allows a subsequent exposure of the components to air for maintenance or component change. Because of the low vapor pressure of typical precursors vaporized using the methods and apparatus of the present invention, without the solvent flush capability residual precursor vapors within conduits would not be sufficiently evacuated nor achieve reduced pressures in a timely—commercially viable—manner simply using only pumping system **355** of exhaust system **300**. Additionally, the solvent flush feature can be used to remove precursor vapor from process conduits and components to prevent risk of exposure to potentially hazardous materials during maintenance as well as prevent the undesired reaction of precursor vapor with air, water vapor, or other materials.

[0144] FIG. 16 is a schematic drawing of a representative LDS and vapor delivery system with one vaporizer and FIG. 17 is a schematic drawing of a representative LDS and vapor delivery system with two vaporizers. FIGS. 16 and 17 allow a better understanding of an integrated method of operating processing system **100** and the use and interoperability of dopant, second dielectric, or second precursor materials within the various embodiments of the present invention. FIG. 16 schematically represents a system configuration using a single vaporizer and process heat exchanger to provide process gas/precursor vapor mixtures through temperature controlled conduits to processing region **202**.

[0145] FIG. 17 is similar to FIG. 16 with the addition of a second vaporizer **521**, bulk container **504** and by-pass valve **570**. Flow through second vaporizer **521** is controlled as discussed regarding vaporizer **520**, but for clarity the elements associated with a second liquid flow controller are not shown. Under the representative configuration of FIG. 17, processing system **100** of the present invention is further enabled to not only provide, mix, and deposit films from a single precursor, but also, by modifying the liquid source contained in bulk container **504**, films containing a second precursor, a dopant, or a metal.

[0146] Processing system **100** as embodied in FIG. 17 operates similarly to previous descriptions of processing system **100** with the addition of an additional bulk container **504**, which could be under a pressure head as with bulk supply container **503**. Bulk container **504** is coupled to and supplies processing fluids to a second vaporizer **521**, which operates similarly to the first vaporizer **520** as embodied in FIG. 16 and described above. The vaporized precursor stream created by the second vaporizer **521** is provided to a chamber by-pass valve **570** that connects, via outlet **571**, the vaporized gas stream to chamber assembly **200** via process gas supply line **586**. Alternatively, by-pass valve **570** can connect the vaporized precursor stream to exhaust system **300** via outlet **572**. Temperature control methods described above are used to provide temperature controlled conduits to provide low vapor pressure precursors to second vaporizer **521** and to convey vapor from vaporizer **521** to processing region **202**. In addition, the components associated with

second vaporizer **521** are equipped like the components associated with vaporizer **520** to heat the carrier gas and the vaporized precursor/carrier gas mixture.

[0147] Another object of the vapor delivery system **500** of the present invention is the deposition of a variety of films on substrates **201** within process area **202** by advantageously selecting precursors for bulk containers **503**, **504**, process gases or carrier gases for gas source **579**, and by selective positioning of by-pass valves **545** and **570**. One advantage of the 2 vaporizer—2 by-pass configuration of **FIG. 17** is that each vaporizer may be in operation and producing stable, repeatable flow that could be easily ported to process region **202** or exhaust system **300** by aligning the appropriate by-pass valve **545** or **570**.

[0148] Referring now to **FIG. 18**, which is an alternative embodiment of aspects of the liquid and vapor delivery systems of **FIGS. 2-17**, this configuration of the invention employs the same functional relationships between the components as discussed with reference to **FIGS. 2-17**, but in an alternative layout where liquid flow meter **510** and vaporizer **520** are arranged horizontally relative to each other in a vaporizer box **502**.

[0149] Now referring to **FIG. 19**, which is a schematic drawing of a second representative LDS and vapor delivery system with two vaporizers, this embodiment includes a second vaporizer **521** and the corresponding components (not shown) that supply vaporizer **521** with precursor fluid, solvent, and carrier gas as supplied to vaporizer **520**, such as a second liquid flow meter **510'**, a second three-way inlet valve **588'**, a second carrier gas supply line **532'**, a second carrier gas heat exchanger **530'**, and a second positive shut-off valve **522'**. In this embodiment the vaporized precursor exits vaporizer **521** and flows through vaporizer outlet conduit **543** directly into vaporizer outlet manifold **542**. Thus, vaporized precursor from both vaporizers **520**, **521** enters and is directed by by-pass valve **545** to either heated feed-through line **560** or by-pass line **322**.

[0150] Referring now to **FIG. 20**, which is an alternative embodiment of the liquid and vapor delivery systems of **FIG. 19**, this configuration of the invention employs the same functional relationships between the components as discussed with reference to **FIG. 19**. But in this alternative layout liquid flow meters **510**, **510'** and vaporizers **520**, **521** are arranged horizontally relative to each other in a vaporizer box **502**, somewhat akin to the configuration of **FIG. 18**. Vaporizer box **502** with spill pan **514** encloses the vaporizers in a manner similar to LDS housing **108** of **FIG. 4**. Vaporizer box **502** has slotted plates **111** that interact with horizontal slots **112** that are shown about the interior base of vaporizer box **502**. House exhaust is attached through exhaust port **501** (**FIG. 12**), drawing air through horizontal slots **112**. Slotted plates **111** adjust as discussed with reference to **FIG. 4** to tune the vaporizer box exhaust flow, although slotted plates **111** in **FIG. 20** are modified to be tuned in a side-to-side fashion. Optical switch **506** detects whether any liquid is present in spill pan **514**. Optical switch **506** is an interlocked hardware switch that de-energizes the gas and precursor control valves as listed in Table I. Also, as part of the interlock system, a sensor (not shown) monitors airflow through exhaust port **501** (**FIG. 12**) via a sensor port **516** (**FIG. 12**) and the system de-energizes the gas and precursor control valves should the flow be too low, as listed

below in Table I. Although it is not shown in **FIG. 4**, LDS housing **108** may also be fitted with a spill pan and an interlocked optical switch in the manner of vaporizer box **502**.

[0151] **FIG. 21** is a schematic of an embodiment of the present invention with two vaporizers mounted on the chamber lid. In this embodiment dual independent temperature controlled vaporizers **520**, **521** are mounted on chamber lid **205** along with many of the components of two vapor delivery systems **500** to create a chamber lid/vaporizer assembly **800**. Mounting vaporizer delivery systems **500** on the chamber lid **205** minimizes the heated path of the vaporized precursor materials from the point of vaporization in vaporizers **520**, **521** to processing region **202**. Similarly numbered elements function as discussed with reference to the earlier embodiments depicted in **FIGS. 2-16**.

[0152] Chamber lid/vaporizer assembly **800** also generally incorporates oxidizer (process) gas heater **582**, carrier gas heat exchangers **530**, **530'**, three-way inlet valves **588**, **588'**, liquid flow meters **510**, **510'**, positive shut off valves **522**, **522'**, vapor delivery manifolds **802**, **803**, union block **826**, valve block **828**, inlet and mixing block **830**, liquid spill detector **804** (**FIG. 27**), cover interlock switch **806** (**FIG. 27**), flexible double-contained liquid lines **700**, **707**, **708**, and heated plasma manifold **270**.

[0153] Carrier gases from carrier sources **531**, **531'** and process gas from process gas source **579** enter chamber lid/vaporizer assembly **800** through chamber lid **205** in the manner depicted in **FIG. 10** with respect to process gas (elements **227/228**). Briefly restated, these gases each pass through a chamber feed-through **227**, **815**, **817** and lid bore-through **228**, **816**, **818** for the process gas and carrier gases, respectively. O-rings are used in the transitions from chamber bore-through to lid bore-through to maintain passageway integrity.

[0154] Process gas from source **579** is heated by process gas heater **582** and enters inlet and mixing block **830** (shown more clearly in **FIG. 26**). Carrier gas from source **531** is heated by carrier gas heat exchanger **530** before entering vaporizer **520**. Similarly, carrier gas from source **531'** is heated by carrier gas heat exchanger **530'** before entering vaporizer **521**. Precursor from container **503** enters chamber lid assembly through flexible double-contained liquid line **708**, passes through three-way inlet valve **588**, liquid flow meter **510**, and positive shut off valve **522**, before entering vaporizer **520**. Similarly, precursor from container **504** enters chamber lid assembly through flexible double-contained liquid line **707**, passes through three-way inlet valve **588'**, liquid flow meter **510'**, and positive shut off valve **522'**, before entering vaporizer **521**. Solvent from container **589** enters chamber lid assembly through flexible double-contained liquid line **700** and flows through solvent delivery line **591** to both three-way inlet valves **588**, **588'**. Thus, as with the embodiment depicted in **FIG. 2**, three-way inlet valves **588**, **588'** may supply either precursor liquid or a solvent to their respective liquid flow meters, with the solvent used to flush the system for maintenance.

[0155] Vaporizers **520**, **521** are mounted to vapor delivery manifolds **802**, **803** respectively. In this embodiment, each liquid flow meter **510**, **510'** also includes a metering valve **524** (**FIG. 15**) and flow meters **510**, **510'** control precursor flow as described with reference to **FIG. 15**. Precursor liquid

passes from positive shut-off valves **522**, **522'** to vaporizers **520**, **521**, respectively, which vaporize the liquid as discussed earlier with reference to FIGS. 2-16. Vaporizers **520**, **521** then deliver the vapor to vapor delivery manifolds **802**, **803**, which in one embodiment have 0.500" diameter internal conduits **808**. Delivery manifolds **802**, **803** in turn deliver the vaporized precursor materials and carrier gas to common conduit **810** within union block **826**. Common conduit **810** conveys the merged precursor materials and carrier gas to by-pass valve **545** that is within valve block **828**. By-pass valve **545** functions as described with reference to FIG. 10 and either conveys the vapor to by-pass line **322**, or to common conduit **811** that lies within mixing block **830**. Common conduit **811** conveys the 2-precursor/carrier gas mixture to central conduit **834**.

[0156] In a further aspect of this invention, common conduit **811** directs flow toward process gas inlet conduit **832** and process gas inlet conduit **832** directs flow toward common conduit **811**. Thus, the process gas injection point of process gas inlet conduit **832** is opposed to common conduit **811** across central conduit **834**. This opposed flow causes turbulence that ensures good mixing of the process gas with the vaporized precursors.

[0157] Central conduit **834** directs the mixture of vaporized precursors and process gas through conduit **230** in lid **205** and the precursors and gas pass through blocker plate **237** and showerhead **240** on the way to processing region **202** as discussed with reference to the embodiment depicted in FIG. 6.

[0158] Heated plasma manifold **270** is also connected to the mixing block **830** to deliver an activated species cleaning gas to processing region **202**. The activated species, described earlier in FIG. 13, passes through chamber feed-through **229** and lid bore-through **221** and within conduit **271** through manifold **270** and block **830** before merging with mixing conduit **834**.

[0159] The embodiment depicted in FIG. 21 maximizes the advantages gained by decreasing the distance from the vaporizer to the processing region, but functions generally as discussed with respect to FIGS. 2-18, as do the individual components. Differences exist between this embodiment and the earlier embodiments in the flow path from the vaporizers to the processing region. Specifically, when vaporizers **520**, **521** were discussed with reference to FIGS. 2-18, each vaporizer directed vapor to individual by-pass valves **545**, **570**. In the chamber lid/vaporizer assembly embodiment depicted in FIGS. 19, 20, 23, 24, 27, 28, and 29 both vaporizers **520**, **521** direct vapor to the same by-pass valve in the manner of the embodiment depicted in FIG. 19.

[0160] Also, in this embodiment, the pressure of each carrier gas is monitored upstream of the vaporization frit (not shown) within vaporizers **520**, **521** using 100 Torr capacitance manometers (not shown). This allows the carrier gas inlet pressure to be periodically checked to determine if the vaporization frit is becoming clogged or needs maintenance. FIG. 21 also illustrates by dotted line the valves that are controlled by on-board software control module **1000**. Although they are not illustrated in the earlier figures, similar connections from on-board software control module **1000** to pedestal heater controllers, power supplies, and various system monitors (such as pressure transducers, exhaust flow monitors, and pump signals) exist and facilitate

the interlocks of Table I, below, and the automation of many aspects of the operation of the present invention.

[0161] FIG. 22 is a perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid. The functional description of FIG. 21 applies equally to FIG. 22. In this embodiment, delivery manifolds **802**, **803**, union block **826**, valve block **828** (FIGS. 23, 29) heated plasma manifold **270**, and mixing block **830** are attached directly to each other. O-rings maintain the integrity of the conduits **808**, **810**, **811**, **271** as they transition from one block to the next.

[0162] This view shows that delivery manifolds **802**, **803** and union block **826** are independently heated using heater cartridges, such as heater cartridge **264**. It is not shown, but valve block **828**, mixing block **830**, and heated plasma manifold **270** are also similarly independently heated. In this embodiment heater cartridges **264** are 208V cartridges of various power ratings. Each block has embedded thermocouples **204** for monitoring the temperature and providing feedback to the temperature controllers. Each manifold and, vaporizer section is independently controlled by separate temperature controllers that allow each section to have different temperature set-points if needed as discussed with regard to the embodiment depicted in FIG. 2. The cartridge heater **264**, thermocouple, and controller function was described in detail with reference to block **262** and manifold **272** of FIG. 6. Again, for clarity, the separate thermocouples and controllers have been mostly omitted, but, in this embodiment, these controllers work to independently control nine sections, are provided with over-temperature switches **209** (shown in manifolds **802**, **803**), and are capable of heating up to 230° C. In an embodiment of the invention, delivery manifolds **802**, **803**, union block **826**, valve block **828**, and mixing block **830** are heated to operate at temperatures of from 30° C. to 230° C. As part of the interlock system, over-temperature switches **209** switch off the related heater circuit should the temperature go too high, as listed in Table I below. In an embodiment of the invention, there are six independently controlled sections between vaporizers **520**, **521** and central lid bore-through **230**.

[0163] In this embodiment of the invention, by-pass valve **545** (FIG. 21) is implemented using a combination of two pneumatic on/off valves **546** (FIG. 26), **547** (FIG. 27) that are controlled by on-board software control module **1000** (FIG. 21). Both valves **546**, **547** (FIG. 27) are normally closed. Valve **546** controls flow from common conduit **810** (FIG. 21) to common conduit **811** (FIG. 21). Valve **547** (FIG. 27) controls flow from common conduit **810** to by-pass line **322** (FIG. 21). By-pass line **322** (not shown in FIG. 22 for clarity) is a flexible vacuum hose that exits chamber lid/vaporizer assembly **800** through a hole in a lid cover **822** (FIG. 25) to eventually connect to chamber by-pass inlet **320** as depicted in FIG. 2. In this embodiment, three-way inlet valves **588**, **588'** are each a similar combination of two pneumatic on/off valves that are controlled by on-board software control module **1000** (FIG. 21).

[0164] With chamber lid/vaporizer assembly **800**, precursor liquids and solvent arrive through lid shelf **812** to precursor supply lines **508**, **508'** and solvent delivery line **591**. Lid shelf **812** translates and rotates when chamber lid **205** is opened. The apparatus for conveying precursor liq-

uids from bulk containers **503**, **504**, and solvent container **589** to chamber lid/vaporizer assembly **800** must accommodate this lid movement.

[0165] Now referring to **FIG. 23**, which is a cross-sectional view of an embodiment of the flexible double containment line of the present invention, flexible double-contained liquid lines **700**, **707** (**FIG. 25**), and **708** (**FIG. 24**) flex to accommodate the movement of lid shelf **812**. Flexible double-contained liquid line **700** contains a primary line **702** within a larger secondary line **704** and endcaps **710**, **712**. Secondary line **704** also prevents material loss should primary line **702** develop a leak. Both primary line **702** and secondary line **704** are equipped with flexible sections **703** and **705**, respectively, that allow flexible double-contained liquid line **700** to bend. Volume **706** is defined by the space between primary line **702**, secondary line **704**, the endcaps **710**, **712**, rigid primary line **714**, and rigid secondary line **716**. Primary line **702** is connected to rigid primary line **714** at connector **718**. Rigid primary line **714** extends through endcap **712** at hole **720**, through LDS housing **108** (**FIG. 24**), and is connected to a bulk storage container (not shown). Hole **720** is larger than rigid primary line **714** so that annular volume **706** continues between rigid primary line **714** and endcap **712**. Rigid secondary line **716** is connected to endcap **712** about rigid primary line **714** and houses rigid primary line **714** until line **714** passes through LDS housing **108**. Where rigid primary line **714** enters LDS housing **108**, the annular space between rigid secondary line **716** and rigid primary line **714** is sealed. Thus, annular volume **706** extends through endcap **712**, between rigid primary line **714** and rigid secondary line **716** to the point where rigid secondary line **716** is sealed to rigid primary line **714**.

[0166] Volume **706** is pressurized and monitored by a pressure monitor **701**. The pressure in volume **706** is adjusted to be higher than any attained within primary line **702** during processing. Therefore, if primary line **702** develops a leak during processing, the pressure in volume **706** will drop. The liquid deposition system is interlocked to pressure monitor **701** so that, should the monitor detect a pressure drop, the liquid deposition system and any other interlocked system will shut down, similar to the conditions indicated by Table I for a LDS spill below. A typical pressure in volume **706** is about 60 p.s.i. In one embodiment, primary flexible section **703** is 0.125" O.D. (0.055" I.D.) line, rigid primary line has a 0.125" O.D., and rigid secondary line has a 0.25" O.D. Flexible double-contained liquid lines **707**, **708** (**FIG. 22**) have the same construction as line **700**.

[0167] Referring now to **FIG. 25**, which is a perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid with the chamber lid/vaporizer assembly in the open position, flexible double-contained liquid lines **700**, **707** are flexed because chamber lid/vaporizer assembly **800** is in the open position. The entire chamber lid/vaporizer assembly **800** is enclosed by an exhausted lid cover **822** (depicted translucently) that is designed to properly exhaust escaped gas and liquid to the foreline system. Lid cover **822** is larger than the previous cover **203** (**FIG. 3**) to accommodate the elements of two

vaporizer systems. Both lid cover **822** and spill rail **824** cooperate to prevent operator exposure to hazardous or hot materials.

[0168] Now referring to **FIG. 26**, which is a second perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid, oxidizer gas enters mixing block **830** from the side opposite from vaporizers **520**, **521** and on/off valve **546**. Also, in this figure, mixing block **830** has been arbitrarily divided into an upper mixing block **830A** and a lower mixing block **830B** for descriptive purposes. In this embodiment process gas enters upper mixing block **830A** via process gas supply line **586** and process gas inlet conduit **832** (**FIG. 21**). Vaporized precursor enters upper mixing block **830A** via common conduit **811** (**FIG. 21**). Plasma enters lower mixing block **830B** through heated plasma manifold **270** and activated species conduit **271** (**FIG. 21**).

[0169] Advancing to **FIG. 27**, which is a third perspective view of an embodiment of the present invention with two vaporizers mounted on the chamber lid, aspects of the embodiment of chamber lid/vaporizer assembly **800** appear more clearly. Chamber lid **205** is designed with a spill rail **824** that captures and contains a liquid spill when chamber lid **205** is horizontal. Chamber lid/vaporizer assembly **800** is also equipped with liquid spill detector **804** and cover interlock switch **806**. Spill detector **804** and cover interlock switch **806** are hardware switches that cause parts of the system to stop functioning as described in the "result" column of Table I should their status meet the criteria described in the "trip cause" column. Additionally, **FIG. 27** further illustrates the relative positioning of vaporizers **520**, **521**, on/off valve **547**, and valve block **828** above heated plasma manifold **270**.

[0170] Many systems associated with chamber assembly **100** are interlocked. An interlock may be a hardware switch, or part of on-board software control system **1000** (**FIG. 21**) that, when activated or "tripped," prevents the continued operation of the interlocked system. A condition that activates an interlock is, thus, known as a "trip cause." Interlocked chamber assembly systems generally stop power to the heaters and prevent gas flows when the interlock is tripped. Most interlocks are designed so that the trip causes (which may be hard-wired circuits or software signals) are connected in series with the interlocked system. When any one of the trip causes in the series occurs, the interlocked system will be de-activated. One embodiment of the invention employs a series of electrical relays as interlocks, where a trip cause with opens an individual relay and stops power to the system. The interlocked systems of chamber assembly **100** are listed in the Result column of Table I which also contains the interlock name, trip cause, and whether the system is shut down via a hardware switch or software control. For example, chamber lid **205** is fitted with a position detector (not shown) that monitors the position of chamber lid **205** relative to chamber body **210**. This position detector is normally open, and completes a circuit when lid **205** is closed. Chamber lid **205** is also interlocked so that it will not open if the pressure within processing region **202** is above 10 Torr. As listed in Table I, the systems that introduce material into processing region **202** or that heat processing region **202** are interlocked to the position detector and the pressure detector.

TABLE I

Interlock	Trip Cause	Result	Hardware or Software
Chamber Lid	Open chamber lid	Gas valves, heaters, chamber de-energized	Hardware Switch
Over Pressure	Chamber over pressure	Gas valves, heaters, chamber de-energized	Pressure transducer monitored by software and Hardware Switch
H ₂ O Flow Low Flow	Low H ₂ O flow at one of the cooling loops	Water heater and multi loop heater controller power de-energized	Hardware relay control
Liquid Leak Detector Action	Optical switch in spill pan	Gas and precursor valves de-energized	Hardware switch
Roughing Pump OK	Loss of OK signal from pump	Gas, precursor valves and heater de-energized	Hardware switch
Liquid Delivery System (LDS) Exhaust	Loss of ventilation to LDS	Gas and precursor valves in LDS and vaporizer de-energized	Hardware switch
LDS Spill	Leak detected in LDS spill pan	Gas and precursor valves in LDS and vaporizer de-energized	Hardware switch
LDS Door	Magnetic proximity switch on door is open	Gas and precursor valves de-energized	Hardware switch
Vaporizer Spill	Leak Detected in LDS spill pan	Gas and precursor valves de-energized	Hardware switch
Vaporizer Exhaust	Loss of ventilation to vaporizer	Gas and precursor valves de-energized	Hardware switch
Over-Temp Switch	Thermal control failure	Snap switch opens supply line to heater blanket	Hardware switch

[0171] It is a further aspect of the invention that the chamber assembly is partly automated by on-board software control module **1000**. Referring to **FIG. 28**, which is a flow chart illustrating automation of the processing system according to an embodiment of the invention, sub-systems of processing system **100** send input **1002** to control module **1000**. Software **1006** receives the input at step **1008**, analyzes the input at step **1010**, commands the appropriate elements of the sub-system(s) at step **1012** to perform responsive procedures by sending orders **1004**, and notifies the user at step **1014** through a display (not shown) associated with control module **1000**.

[0172] In one embodiment, software **1006** controls aspects of the gas and vapor delivery systems during system maintenance. For example, when system operators need to change a near-empty bulk storage container **503, 504** (**FIGS. 14, 16, and 17**) for a full container, gauges (not shown) in the bulk storage containers provide input **1002** to on-board software control module **1000** that a storage container is near empty. Software **1006** receives the input at step **1008** from the gauges, analyzes the input at step **1010**, and commands the sub-system at step **1012**, in this case vapor delivery system **500**, to perform procedures that are associated with changing a bulk container. In this instance, when the bulk storage containers are empty, orders **1004** will stop power to the processing system.

[0173] Software **1006** is also employed during maintenance to run sub-routines called for by steps in the maintenance manual for processing system **100**. In this manner, software **1006** receives directions from the operator as input at step **1008**, as well as input from the processing systems **100**. For example, software **1006** may be directed to run sub-routines that direct the sub-systems of processing system **100** to perform these other functions as well: 1) relieving pressure in the bulk storage containers **503, 504**; 2) evacuating solvent delivery line **591**; 3) Evacuating and

re-charging the lines down stream of three-way inlet valves **588, 588'** after a liquid flow meter or vaporizer component change; 4) purging precursor liquid lines from near the bulk storage containers **503, 504** to by-pass valve **545**; 5) flushing solvent deliver line **591** with solvent and helium after a precursor bulk storage container change; 6) evacuating precursor liquid supply lines from precursor bulk storage container to by-pass valve **545**; 7) charging precursor delivery supply lines between precursor bulk storage container and chamber with precursor; 8) flushing liquid flow meters **510, 510'** and vaporizers **520, 521** with solvent; 9) purging liquid flow meters **510, 510'** and vaporizers **520, 521** with helium; 10) flushing the lines from bulk storage supply containers to liquid flow meters with solvent and pumping them down; 11) relieving the pressure in the solvent bulk storage container; 12) evacuating solvent delivery line **591** for bulk storage container change; and 13) charging precursor supply lines **508, 508'** after changing bulk storage containers.

[0174] Also, on-board computer control module **1000** and software **1006** are part of the interlock that commands a sub-system to shut down in case of a system overpressure and the interlock that commands a sub-system to shut down in case of the loss of the roughing pump OK signal, as listed in Table I.

[0175] It is to be understood that while illustrative embodiments of the invention have been shown and described herein, various changes and adaptations in accordance with the teachings of the invention will be apparent to those of ordinary skill in the art. Such changes and adaptations nevertheless are included within the spirit and scope of the invention as defined in the following claims.

We claim:

1. An apparatus for depositing a film, said apparatus comprising:

- a chamber assembly comprising a chamber body and a processing region;
- a first vaporizer; and
- a vapor delivery system connecting said first vaporizer and said processing region with a first vapor path of less than approximately three feet from said first vaporizer through said vapor delivery system to said processing region.

2. The apparatus of claim 1, wherein said vapor delivery system further comprises:

- a plurality of heated zones;
- a heater in thermal contact with each said heated zone;
- a thermocouple in thermal contact with each said heated zone; and
- a plurality of temperature controllers, wherein each of said plurality of temperature controllers is in communication with a heater and thermocouple in a different one of said plurality of heated zones to maintain said heated zones at a first target temperature.

3. The apparatus of claim 1, wherein said vapor delivery system further comprises:

- a plurality of heated zones;
- a heater in thermal contact with each said heated zone;
- a thermocouple in thermal contact with each said heated zone; and
- a plurality of temperature controllers, wherein each of said plurality of temperature controllers is in communication with a heater and thermocouple in a different one of said plurality of heated zones to maintain at least one of said heated zones at a first target temperature and another of said heated zones at a second target temperature.

4. The apparatus of claim 1, wherein said chamber assembly further comprises a chamber lid and a sealing O-ring, and said chamber lid comprises:

- a temperature controlled lid zone, with said temperature controlled lid zone in thermal contact with said sealing O-ring;
- a passageway in thermal contact with said temperature controlled lid zone wherein a temperature controlled liquid is conveyed through said passageway to cool said temperature controlled lid zone; and
- a heated lid zone in thermal contact with said processing region.

5. The apparatus of claim 1, said vapor delivery system further comprising a first vapor three-way valve between said first vaporizer and said processing region, said first vapor three-way valve connecting said first vaporizer to said processing region or to an exhaust system.

6. The apparatus of claim 1, further comprising a liquid delivery system comprising:

- a first precursor container for holding a first precursor;
- a solvent container for holding a solvent; and

a liquid three-way valve, said liquid delivery system connecting said first vaporizer to said liquid three-way valve and said liquid three-way valve connecting said vaporizer to said first precursor container or to said solvent container.

7. The apparatus of claim 6, said liquid delivery system further comprising a liquid flow meter between said liquid three-way valve and said first vaporizer, and said vaporizer comprising a metering valve.

8. The apparatus of claim 7, said liquid delivery system further comprising a positive shut off valve between said liquid flow meter and said first vaporizer.

9. The apparatus of claim 1, said chamber assembly further comprising:

- a chamber body;
- a passageway in thermal contact with said chamber body;
- a chamber body fluid thermocouple in thermal contact with a chamber body fluid within said passageway;
- a chamber body fluid heater;
- and a chamber body fluid temperature controller, wherein said chamber body fluid temperature controller communicates with said chamber body fluid thermocouple and regulates chamber body fluid heater to keep said chamber body fluid at a target chamber body temperature.

10. The apparatus of claim 9 wherein said chamber body fluid is heated.

11. The apparatus of claim 1, said chamber assembly further comprising:

- a cavity within said chamber body;
- a chamber liner proportioned to conform to said cavity; and
- a region comprising a gap between said chamber body and said chamber liner.

12. The apparatus of claim 11 wherein said gap is about 0.100 inches.

13. The apparatus of claim 1 further comprising:

- a pedestal heater comprising a center region and an annular region about said center region;
- at least one heater in thermal contact with said center and annular regions;
- at least one thermocouple in thermal contact with said center region;
- at least one temperature controller, wherein said heaters, thermocouples, and temperature controller cooperate to heat each of said center region and said annular region to a first support temperature, and wherein said temperature controller directs said heaters to heat to said annular region based on an amount said temperature controller directs said heaters to heat said center region.

14. The apparatus of claim 1 further comprising:

- an enclosed volume within said chamber assembly;
- a pedestal heater housed within said chamber assembly;
- a seam between said pedestal heater and said chamber body whereby a gas can flow between said processing region and said enclosed volume; and
- a gas inlet connected to said enclosed volume.

15. The apparatus of claim 14 wherein said pedestal heater partially defines both said processing region and said enclosed volume.

16. The apparatus of claim 1 further comprising a second vaporizer, wherein:

said vapor delivery system connects said second vaporizer and said processing region with a second vapor path of less than approximately three feet from said second vaporizer through said vapor delivery system to said processing region.

17. The apparatus of claim 16, said vapor delivery system further comprising

a first vapor three-way valve between said first and second vaporizers and said processing region, said first vapor three-way valve connecting both said first and second vaporizers to said processing region or to an exhaust system.

18. The apparatus of claim 16, said vapor delivery system further comprising:

a first vapor three-way valve between said first vaporizer and said processing region; and

a second vapor three-way valve between said second vaporizer and said processing region, wherein said first vapor three-way valve connects said first vaporizer to said processing region or to an exhaust system and said second vapor three-way valve connects said second vaporizer to said processing region or to said exhaust system.

19. The apparatus of claim 16, further comprising a liquid delivery system comprising:

a first precursor container for holding a first precursor;

a second precursor container for holding a second precursor;

a solvent container for holding a solvent; and

a first liquid three-way valve and a second liquid three-way valve, and wherein said liquid delivery system connects:

said first vaporizer to said first liquid three-way valve;

said first liquid three-way valve to both said first precursor container and said solvent container;

said second vaporizer to said second liquid three-way valve; and

said second liquid three-way valve to both said second precursor container and said solvent container.

20. The apparatus of claim 1, wherein:

said chamber assembly further comprises a chamber lid; and

said vapor delivery system further comprises a vapor delivery manifold wherein:

said vapor delivery manifold is mounted on said chamber lid;

said first vaporizer is mounted on said vapor delivery manifold; and

said vapor delivery manifold connects said first vaporizer to said processing region.

21. The apparatus of claim 20, wherein said chamber lid is hingedly attached to said chamber body and partly defines said processing region.

22. The apparatus of claim 16, wherein:

said chamber assembly further comprises a chamber lid; and

said vapor delivery system further comprises a vapor delivery manifold wherein:

said vapor delivery manifold is mounted on said chamber lid;

said first and second vaporizers are mounted on said vapor delivery manifold; and

said vapor delivery manifold connect said first and second vaporizers to said processing region.

23. The apparatus of claim 22 wherein said chamber lid is hingedly attached to said chamber body and partly defines said processing region.

24. The apparatus of claim 22, said vapor delivery system further comprising a vapor three-way valve mounted on said vapor delivery manifold, wherein:

said vapor delivery manifold connects:

said first and second vaporizers to said vapor three-way valve; and

said vapor three-way valve to said processing region and to an exhaust system.

25. The apparatus of claim 22 further comprising a liquid delivery system comprising a first flexible double containment line, said first flexible double containment line comprising:

an outer tube comprising a first flexible section;

an inner tube comprising a second flexible section, wherein said inner tube passes through said outer tube to create an annular space, and wherein said second flexible section is primarily within said first flexible section; and

a plurality of annular plugs that are positioned to enclose said annular space to create an annular volume, said flexible double containment line positioned to flex to accommodate movement of said chamber lid.

26. The apparatus of claim 25 wherein a gas fills said annular volume and creates a pressure within said annular volume.

27. The apparatus of claim 25, wherein at least one said annular plugs comprises a weld.

28. The apparatus of claim 26, further comprising:

a processing system, said processing system comprising at least one valve and at least one heater;

a pressure monitor in communication with said annular volume;

a hardware interlock; and

a software control module comprising software that monitors said pressure monitor, wherein said hardware interlock de-energizes said at least one valve, said at least one heater, and said chamber assembly when said software detects a pressure change in said annular volume.

29. The apparatus of claim 25, said liquid delivery system further comprising:

- a first precursor container for holding a first precursor;
- a second precursor container for holding a second precursor;
- a solvent container for holding a solvent;
- a second flexible double containment line similar to said first double containment line;
- a third flexible double containment line similar to said first double containment line;
- a first liquid three-way valve; and
- a second liquid three-way valve, wherein said liquid delivery system connects:
 - said first vaporizer to said first liquid three-way valve;
 - said first liquid three-way valve to said first precursor container using said first flexible double containment line and to said solvent container using said second double containment line;
 - said second vaporizer to said second liquid three-way valve; and
 - said second liquid three-way valve to said second precursor container using said third flexible double containment line and to said solvent container using said second double containment line.

30. The apparatus of claim 22, said vapor delivery manifold further comprising:

- a vapor conduit;
- a process gas conduit; and
- a mixing conduit, wherein said vapor conduit and said process gas conduit intersect said mixing gas conduit at a first intersection such that a vapor exiting said vapor conduit is directed towards a process gas as said process gas exits said process gas conduit and said process gas is directed towards said vapor as said vapor exits said vapor conduit.

31. The apparatus of claim 1 further comprising a tunable exhaust system, said tunable exhaust system comprising:

- a slotted housing comprising first and second slotted housing wall regions, each with a plurality of ventilation slots;
- a plurality of slotted plates, each slidably attached to a corresponding area of said first or second slotted housing wall regions whereby sliding each said slotted plate in an opening direction uncovers said ventilation slots in said corresponding area and sliding each said slotted plate against said slotted housing wall region in a closing direction covers said ventilation slots in said corresponding area;

an exhaust cover overlaying said first slotted wall region to create an enclosed volume; and

an exhaust port in said exhaust cover for attaching to an exhaust line.

32. The apparatus of claim 31 wherein said slotted housing comprises a pair of parallel walls and said first slotted

housing wall region is on one said parallel wall and said second slotted housing wall region is on the other of said parallel walls.

33. The apparatus of claim 31 wherein said slotted housing comprises a pair of perpendicular walls and said first slotted housing wall region is on one said perpendicular wall and said second slotted housing wall region is on the other of said perpendicular walls.

34. The apparatus of claim 31 wherein said slotted housing houses a liquid delivery system.

35. The apparatus of claim 31 wherein said slotted housing houses a vapor delivery system.

36. The apparatus of claim 1 further comprising a lift mechanism, said lift mechanism comprising:

a pedestal heater with an upper surface and a plurality of holes spaced about said heater and oriented perpendicularly to said upper surface;

a lift plate;

a lift tube supporting said lift plate;

a plurality of lift pins dimensioned to move within said plurality of holes, extend through said pedestal heater, and contact said lift tube;

a shaft supporting said pedestal heater;

a lower carrier supporting said shaft;

an upper carrier supporting said lift tube; and

an upper retainer, wherein:

said lower carrier and said shaft cooperate to raise and lower said pedestal heater to an upper position, a lower position, and an intermediate position;

said lift pins move, between a raised position above said upper surface of said pedestal heater and a lowered position even with or below said upper surface, as a result of relative movement between said pedestal heater and said lift plate;

said upper carrier:

rests against said upper retainer during movement by said lower carrier between said upper and intermediate positions so that there is a relative movement between said upper and lower carriers; and

moves in unison with said lower carrier during movement by said lower carrier between said intermediate and lower positions; and

said lift plate contacts said lift pins so that said relative movement causes said lift pins to move between said extended and said retracted positions.

37. The apparatus of claim 36 wherein there are four lift pins evenly spaced about said pedestal heater.

38. The apparatus of claim 36, further comprising:

a motor;

a lead screw drive shaft; and

a nut, wherein said lower carrier is raised and lowered by said motor coupled to said lead screw drive shaft and said nut.

39. The apparatus of claim 36, further comprising a lift housing wherein:

said upper and lower carriers are supported by said lift housing;

said lift housing attaches to said chamber assembly through a lift leveling plate; and

said lift leveling plate adjusts to align said lift mechanism with said chamber assembly.

40. The apparatus of claim 1 further comprising an interlock.

41. The apparatus of claim 40, wherein:

said apparatus further comprises at least one switch connecting said apparatus to a power supply;

said at least one switch has an on and an off position; and

said interlock moves said at least one switch to said off position when said interlock is activated by a trip cause.

42. The apparatus of claim 40, wherein:

said apparatus further comprises at least one valve with an on and an off position; and

said interlock turns at least one said valve to said off position when said interlock is activated by a trip cause.

43. The apparatus of claim 42 further comprising a chamber lid that closes upon said chamber body, wherein said interlock comprises a lid position detector and said trip cause comprises said lid position detector detecting that said chamber lid is open.

44. The apparatus of claim 41 wherein said interlock comprises a spill detector and wherein said trip cause comprises said spill detector detecting a liquid spill.

45. The apparatus of claim 42 wherein said interlock comprises a spill detector and wherein said trip cause comprises said spill detector detecting a liquid spill.

46. The apparatus of claim 40, further comprising a processing system, said processing system comprising at least one valve and at least one heater and said interlock comprises:

a software control module;

software; and

a pressure monitor, wherein said software control module de-energizes said at least one valve, said at least one heater, and said chamber assembly when said software receives a signal from said pressure monitor that said system pressure is too high.

47. The apparatus of claim 20, further comprising:

A flexible double containment line, said containment line comprising:

an outer tube comprising a first flexible section;

an inner tube comprising a second flexible section, wherein said inner tube passes through said outer tube to create an annular space, and wherein said second flexible section is primarily within said first flexible section;

a plurality of annular plugs that are positioned to enclose that portion of said annular space that lies between said first and second flexible sections to create an annular volume; and

a gas, wherein said gas fills said annular volume and creates a pressure within said annular volume.

48. The apparatus of claim 47 further comprising an interlock, and said containment line further comprising a pressure transducer monitoring said pressure, wherein:

said containment line permits a liquid to flow from said container to said vapor delivery system; and

said interlock communicates with said pressure transducer and when said pressure drops below a target level said interlock stops said liquid from flowing from said container to said containment line.

49. A flexible double containment line apparatus comprising:

an outer tube comprising a first flexible section;

an inner tube comprising a second flexible section, wherein said inner tube passes through said outer tube to create an annular space, and wherein said second flexible section is primarily within said first flexible section;

a plurality of annular plugs that are positioned to enclose that portion of said annular space that lies between said first and second flexible sections to create an annular volume; and

a gas, wherein said gas fills said annular volume and creates a pressure within said annular volume.

50. An apparatus for depositing a film, said apparatus comprising:

a chamber assembly comprising a chamber body, a chamber lid, and a processing region;

a first vaporizer;

a vapor delivery system connecting said first vaporizer to said processing region, said vapor delivery system comprising:

a vapor delivery manifold wherein:

said vapor delivery manifold is mounted on said chamber lid;

said first vaporizer is mounted on said vapor delivery manifold; and

said vapor delivery manifold connects said first vaporizer to said processing region.

51. An apparatus for depositing a film, said apparatus comprising:

a chamber assembly-comprising a chamber body, a chamber lid, and a processing region;

a first vaporizer;

a vapor delivery system connecting said first vaporizer to said processing region, said vapor delivery system comprising:

a vapor delivery manifold wherein:

said vapor delivery manifold is mounted on said chamber lid;

said first vaporizer is mounted on said vapor delivery manifold; and

said vapor delivery manifold connects said first vaporizer to said processing region;

a plurality of heated zones;
a heater in thermal contact with each said heated zone;
a thermocouple in thermal contact with each said heated zone; and
a plurality of temperature controllers, wherein each of said plurality of temperature controllers is in communication with a heater and thermocouple in a different one of said plurality of heated zones to independently maintain each said heated zone at a target temperature.

52. The apparatus of claim 51 wherein said plurality of heated zones is six.

53. The apparatus of claim 16, further comprising:

a first metering valve for metering a first flow rate to said first vaporizer;
a second metering valve for metering a second flow rate to said second vaporizer;
a first vaporizer temperature controller for controlling a first vaporization temperature of said first vaporizer; and

a second vaporizer temperature controller for controlling a second vaporization temperature of said second vaporizer, wherein:

said first flow rate may be different from said second flow rate; and

said first vaporization temperature may be different from said second vaporization temperature.

54. The apparatus of claim 1, further comprising a remote plasma generator for introducing an activated species into said processing region.

55. The apparatus of claim 6, further comprising a main-frame, and wherein said liquid delivery system further comprises:

a liquid delivery system housing located on said main-frame;

a plurality of precursor supply lines; and

at least one solvent supply line, wherein:

said liquid delivery system housing is dimensioned to contain a plurality of bulk storage containers and at least one bulk solvent container while said bulk storage containers are connected to said precursor supply lines and said bulk solvent bulk container is connected to said at least one solvent supply line.

56. The apparatus of claim 55 wherein said plurality of bulk storage containers is four and said liquid delivery system housing is within ten feet of said chamber assembly.

57. The apparatus of claim 1, further comprising:

an enclosure for housing said vaporizer;

a spill detector within said enclosure;

a heated zone within said enclosure; and

an interlock, wherein:

said interlock is in communication with said spill detector and said interlock de-energizes said heated zone when said spill detector detects a spill.

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