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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 March 2004 (04.03.2004)

PCT

(10) International Publication Number
WO 2004/018909 A2

(51) International Patent Classification[7]: F16K

(21) International Application Number: PCT/US2003/026139

(22) International Filing Date: 20 August 2003 (20.08.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/405,070 20 August 2002 (20.08.2002) US

(71) Applicant: **APPLIED MATERIALS, INC.** [US/US]; 3050 Bowers Avenue, Santa Clara, CA 95054 (US).

(72) Inventors: **NGUYEN, Anh, H.**; 1075 Columbus Drive, Milpitas, CA 95035 (US). **YUDOVSKY, Joseph**; 594 Smokey Court, Campbell, CA 95008 (US). **ALEXANDER, Mark, A.**; 110 Maywood Drive, Boulder Creek, CA 95006 (US). **YOON, Hungsuk, A.**; 57 Mirabelli Circle, San Jose, CA 95134 (US). **CHEN, Chiliang**; 1712 Calgary Drive, Sunnyvale, CA 94087 (US).

(74) Agents: **PATTERSON, B., Todd** et al.; Moser, Patterson & Sheridan, LLP., 3040 Post Oak Blvd., Suite 1500, Houston, TX 77056 (US).

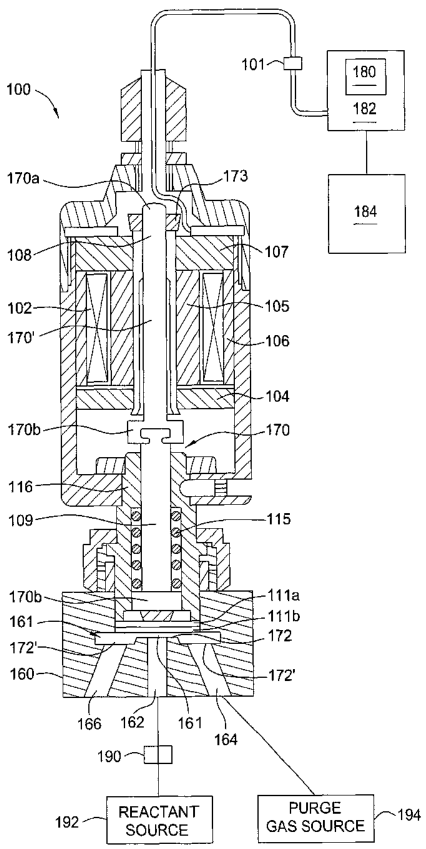
(81) Designated States *(national)*: CA, CN, JP, KR.

(84) Designated States *(regional)*: European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ELECTRONICALLY ACTUATED VALVE



(57) Abstract: The present invention relates to a method and apparatus for delivery of reactants to a substrate processing chamber. An electronically controlled valve assembly is provided for rapid delivery of pulses of reactants to the chamber. The valve assembly comprises a valve body having a valve seat, and at least one gas inlet and one gas outlet below the seat. The piston is selectively movable within the valve body to open and close the valve. In order to actuate the valve assembly, current is sent to a solenoid coil within the valve body. The solenoid coil generates a magnetic field that acts on an adjacent magnetic member. The solenoid coil, magnetic member and piston are arranged such that relative movement of the coil and magnetic member cause the piston to be moved relative to the valve seat.

WO 2004/018909 A2

ELECTRONICALLY ACTUATED VALVE

RELATED APPLICATIONS

[0001] This application claims benefit of United States Provisional Patent Application No. 60/405,070, filed August 20, 2002. That application was entitled "Electronically Actuated Valve," and is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] Embodiments of the present invention relate to a method and apparatus for delivery of one or more reactants to a substrate processing chamber. More particularly, embodiments of the present invention relate to a valve assembly for rapid delivery of pulses of one or more reactants to a substrate processing chamber.

Description of the Related Art

[0003] Reliably producing sub-micron and smaller features is one of the key technologies for the next generation of very large scale integration (VLSI) and ultra large scale integration (ULSI) of semiconductor devices. However, as the fringes of circuit technology are pressed, the shrinking dimensions of interconnects in VLSI and ULSI technology have placed additional demands on the processing capabilities. The multilevel interconnects that lie at the heart of this technology require precise processing of high aspect ratio features, such as vias and other interconnects. Reliable filling of the interconnects is important to VLSI and ULSI success and to the continued effort to increase circuit density and quality of individual substrates.

[0004] As circuit densities increase, the widths of vias, contacts, and other features, as well as the dielectric materials between them, decrease to sub-micron dimensions (e.g., less than 0.20 micrometers or less), whereas the thickness of the dielectric layers remains substantially constant, with the result that the aspect ratios for the features, *i.e.*, their height divided by width, increase. Many traditional deposition processes have difficulty filling sub-micron structures where the aspect ratio exceeds 4:1, and particularly where the aspect ratio exceeds 10:1. Therefore, there is a need for technology that provides for the formation of substantially void-free and seam-free sub-micron features having high aspect ratios.

[0005] Atomic layer deposition is one deposition technique being explored for the deposition of material layers into high aspect ratio vias. An atomic layer deposition (ALD) process is a cyclical deposition method that is generally used for depositing ultra-thin layers (e.g., mono-layers) over features of semiconductor devices having a high aspect ratio.

[0006] One example of atomic layer deposition comprises the sequential introduction of pulses of gases. The ALD process utilizes a chemisorption phenomenon to deposit mono-layers of reactive precursor molecules. During the ALD process, reactive precursors are injected, in the form of pulsed gases, into a deposition chamber in a predetermined cyclical order. Each injection of a precursor provides a new atomic layer on the substrate that is additive to or combines with the previously deposited layers. Injections of individual precursor gases generally are separated by injections of a purge gas. In some instances, the purge gas may be flown continuously into the deposition chamber. The purge gas generally comprises an inert gas, such as argon (Ar), helium (He) and the like, or a mixture thereof. During the ALD process, the deposition chamber is also continuously evacuated to reduce the gas phase reactions between the precursors.

[0007] By way of example, during an ALD operation a first cycle for the sequential introduction of pulses of gases may comprise a pulse of a first reactant gas, followed by a pulse of a purge gas and/or a pump evacuation, followed by a pulse of a second reactant gas, and followed by a pulse of a purge gas and/or a pump evacuation. The term "gas" as used herein is defined to include a single gas or a plurality of gases. Sequential introduction of separate pulses of the first reactant and the second reactant may result in the alternating self-limiting adsorption of monolayers of the reactants on the surface of the substrate, thus forming a thin layer of material for each cycle. The cycle may be repeated to a desired thickness of the deposited material.

[0008] Various problems exist with current gas delivery apparatuses used to perform atomic layer deposition. Examples include slow delivery of reactants, generation of particles, and/or failure over time of components of the gas delivery apparatuses. Therefore, there is a need for new apparatuses and methods to perform gas delivery, such as during an ALD procedure.

SUMMARY OF THE INVENTION

[0009] Embodiments of the present invention generally relate to a method and apparatus for delivery of one or more reactants to a substrate processing chamber. More particularly, embodiments of the present invention relate to a valve assembly for efficient delivery of pulses of one or more reactants to a substrate processing chamber.

[0010] The valve assembly of the present invention is electronically controlled. The valve assembly first comprises a valve body having a valve seat, and at least one gas inlet and one gas outlet below the seat. The piston is slidably movable within the valve body to open and close the valve. Preferably, a diaphragm is disposed at the end of the piston that is dimensioned to seal the flow of fluids through the valve body when the valve assembly is in its closed position, and to permit the flow of fluids through the valve body when the valve assembly is in its open position.

[0011] In order to actuate the valve assembly, current is sent to a solenoid coil within the valve body. The solenoid coil generates a magnetic field that acts on an adjacent magnetic member. When the coil is electromagnetically induced, the solenoid coil and the magnetic member move relatively away from each other. The solenoid coil, magnetic member and piston are arranged such that relative movement of the coil and magnetic member cause the piston to be moved relative to the valve seat.

[0012] The piston may be biased in an open position, such that actuation of the piston causes the valve assembly to be closed. However, it is preferred that the piston be biased in a closed position, such that actuation of the piston causes the valve assembly to be opened. In one embodiment, the valve assembly further includes a diaphragm position indicator so that the movement of the diaphragm at the end of the piston may be confirmed.

[0013] In operation according to one embodiment, a reactant gas source is placed in fluid communication with one inlet, and a purge gas source is placed in fluid communication with another inlet. The valve assembly is normally closed. When current is directed to the solenoid coil, a magnetic field is generated which causes the magnetic member to mechanically act upon the piston. The piston is moved, causing the attached diaphragm to move off of the seat. This, in turn, permits the reactant gas and the purge gas to enter a chamber in the valve body. The chamber is in fluid communication with the gas outlet. The gas outlet, in turn, is in fluid communication with a substrate processing chamber. In this manner, small quantities of gas may be selectively pulsed into a substrate processing chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0015] Figure 1 is a cross-sectional view of an electronically controlled valve assembly of the present invention, in one embodiment. In this arrangement, the valve assembly includes a three-port valve body.

[0016] Figure 2 presents a cross-sectional view of an electronically controlled valve assembly employing a two-port valve body.

[0017] Figure 3 provides a graph of the response time of the piston as it is moved between a closed position and an open position.

[0018] Figure 4 is graph demonstrating current being delivered to the solenoid coil to act as a dynamic break of an electronically controlled valve assembly.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] Embodiments of the present invention relate to a valve assembly for delivery of one or more reactants to a substrate processing chamber. More particularly, embodiments of the present invention relate to a valve assembly for rapid delivery of pulses of one or more reactants to a substrate processing chamber. Reactants can be precursors, reducing agents, oxidizing agents, catalysts, and mixtures thereof.

[0020] **Figure 1** is a cross-sectional view of an electronically controlled valve assembly **100** of the present invention, in one embodiment. The valve assembly **100** first comprises a valve port body **160**. The valve port body includes a valve chamber **161** for receiving different fluids. In the arrangement shown in **Figure 1**, the valve port body **160** defines a three-port valve body **160** for placing the valve chamber **161** in fluid communication with three fluid inlets, or "ports." The three ports are shown at **162**, **164** and **166**.

[0021] In the arrangement of **Figure 1**, the first port **162** serves as a reactant inlet, the second port **164** serves as a purge inlet **164**, and the third port serves as an outlet **166**. The reactant inlet **162** is in fluid communication with a reactant source **192**. The reactant inlet **162** receives a reactant from the reactant source **192** and delivers the reactant into the valve chamber **161**. The purge inlet **164** is in fluid communication with a purge gas source **194**. The purge inlet **164** receives a purge gas from the purge gas source **194** and delivers the purge gas into the valve chamber **161**. In both instances, the gas, e.g., reactant or purge gas, is then expelled by the valve assembly **100** through the outlet **166** and into a substrate processing chamber body (not shown). If the substrate processing chamber includes two or more valve assemblies **100**, the purge inlet **164** of each valve assembly **100** may be coupled to separate purge gas sources or may be coupled to a common purge gas source.

[0022] The valve body **160** includes a valve seat **172**. The valve seat **172** is disposed in the valve chamber **161** at the interface with the three inlets **162**, **164**, **166**. The valve seat **172** receives a valve member **170** that resides within the valve body **160**. Movement of the valve member **170** onto and off of the seat **172** allows the valve assembly **100** to selectively receive gases into the valve chamber **161** through the reactant inlet **162** and the purge inlet **164**, and to expel the reactant gases and purge gases through the outlet **166** and into the substrate processing chamber.

[0023] The valve member **170** first comprises a piston **170'** movable within the valve chamber **161**. The piston **170** is a longitudinal shaft that sealingly resides within the valve body **160** above the seat **172**. The piston **170'** has a proximal end **170a** at a first end of the valve body **160**, and a distal end **170b** that terminates above the seat **172**. In the arrangement of **Figure 1**, the piston **170'** is made of two separate bodies -- a movable shaft **108**, and a valve rod **109** connected to the movable shaft **108**. However, it is understood that the piston **170'** may be a unitary piece.

[0024] The valve member **170** of **Figure 1** next comprises a bonnet **116**. The bonnet **116** defines a longitudinal housing for the valve rod **109**. An upper portion of the bonnet **116** closely receives the rod **109**, while a lower portion of the bonnet **116** has an enlarged inner diameter that forms an annular region around the rod **109**. Within the annular region resides a spring **115**. The spring **115** may be biased in either tension or compression, depending on the direction of desired bias for the piston **170'**. Preferably, the spring **115** serves as a biasing member for urging the distal end **170b** of the piston **170'** downward onto the seat **172**.

[0025] The distal end **170b** of the piston **170'** defines a diaphragm **111**. The diaphragm **111** is preferably made of a nickel alloy, such as a nickel-cobalt alloy. Alternatively, the diaphragm **111** may be made of any suitable material. The diaphragm **111** is configured to close off the reactant inlet **162** and the purge inlet

164 when the valve assembly **100** is in its closed positioned. In the arrangement of **Figure 1**, a peripheral portion of the diaphragm **111** is attached to the bonnet **116**, while an inner portion of the diaphragm **111** is attached to the valve rod **109**. Because the spring **115** preferably urges the valve rod **109** downwardly, the diaphragm **111** is urged against the valve seat **172**. In other embodiments, the valve assembly may be biased in an open position. However, a valve assembly **100** which is biased in a closed position is preferred so that the diaphragm **111** does not accidentally open at the wrong time.

[0026] A magnetic member **104** is placed within the valve body **160**. The magnetic member **104** is concentrically disposed around a portion of the upper shaft **108**. The magnetic member **104** is fabricated from a magnetic material, such as iron, iron/cobalt alloys, iron/nickel alloys, or other suitable materials. A solenoid coil **102** is positioned in parallel with the shaft **108**. The solenoid coil **102** may comprise one or a plurality of coils wrapped around the shaft **108**. The solenoid coil **108** and the magnet **104** operate together to move the valve **170** between its open and closed positions.

[0027] In operation, the piston **170'** and its diaphragm **111** are moved from a closed position to an open position by supplying a current to the solenoid coil **102**. Current is supplied through an electrical connector **101**. The flow of current causes the solenoid coil **102** to be electromagnetically induced. The magnetic flux of the induced solenoid coil **102** causes relative movement between the coil **102** and the magnetic member **104**. In one arrangement, the magnet **104** is mechanically attached to and moves with the shaft **108**, while the position of the solenoid coil **102** is fixed relative to the valve body **160**. In another arrangement, the magnet **104** is mechanically attached to the valve body **160**, while the solenoid **102** is mechanically attached to the shaft **108**. In either instance, the presence of magnetic flux moves the piston **107'**, e.g., the shaft **108** and the connected valve rod **109** and diaphragm **111**.

[0028] As noted above, the diaphragm **111** may either be biased in an open or a closed position. Where the diaphragm **111** is normally open, actuation of the piston **170'** may be by urging the magnet **104** and connected shaft **108** downward. This causes the diaphragm **111** to move downward and to seat. In this way, inlets **162** and **164** are closed. A lower shoulder **170b** is fabricated along the piston **170'** for mechanically engaging the magnet **104**. Where the diaphragm **111** is normally closed, actuation of the valve member **170** may be by urging the solenoid **102** and connected shaft **108** upward. This causes the diaphragm **111** to move upward. As the diaphragm **111** is moved upward, it raises off of the valve seat **172**. In this way, inlets **162** and **164** are selectively opened. An upper shoulder **170a** is fabricated along the piston **170'** for mechanically engaging an upper magnet **107**. In this respect, optional magnetic members **105**, **106**, and/or **107** may be disposed about the solenoid coil **102** to increase the drive force of the magnetic flux of the solenoid coil **102**. These additional magnets would be fixed to the coil **102**.

[0029] While a mechanical engagement arrangement is shown in **Figure 1** for acting upon the piston **170'**, the present invention is not limited to mechanical engagement, but may include electromagnetic force, such as by fabricating the shoulder **173** from a magnetic material having opposite polarity from that of the magnet **107**.

[0030] In order to actuate the valve member **170**, and as noted above, current is provided to the solenoid coil **102**. In one arrangement, current is provided by a driver **180**. Electrical communication is provided between the valve member **170** and the solenoid coil **102** through an electrical connector **101**. Signals are sent through the electrical connector **101** by a programmable logic controller (PLC) **182**. The PLC **182**, in turn, is controlled by a main controller **184**. For example, the main controller **184** signals the programmable logic controller **182** to execute a set of operations. The programmable logic controller **182** signals the main controller **184** when the operations have been executed. The PLC **182** reduces the time required to transmit the set of operations between the main controller **184** and the driver **180**. Preferably, the electrical connector **101** is disposed away from the valve body **160** to reduce the likelihood of disconnection of the electrical connector **101** and the driver **180** from the jarring motion of the shaft **108** and connected valve rod **109**.

[0031] Returning to **Figure 1**, the valve assembly **100** is in its open position. It can be seen that the diaphragm **111** is away from the valve seat **170** to allow the in-flow of a reactant from the reactant inlet **162** or the in-flow of a purge gas from the purge inlet **164**. Gases are allowed to enter the valve chamber **161**, where they flow out through the outlet **166**. From there, gases flow into the substrate processing chamber body.

[0032] In a closed position, the diaphragm **111** is in contact with the valve seat **170** to prevent the in-flow of a reactant from the reactant inlet **162**. In certain preferred embodiments, in its closed position the diaphragm **111** does not block the in-flow of the purge gas from the purge inlet **164**, through the valve chamber **161**, into the outlet **166**, and out to the substrate processing chamber. As shown in **Figure 1**, the valve chamber **161** may further comprise a groove **172'** formed in the valve body **160** below the valve seat **172** so that the purge inlet **164** and the outlet **166** remain in fluid communication whether the diaphragm **111** is in a closed position or an open position. The groove **172'** may be annular in shape as shown, or may be any suitable shape. As a consequence, in one aspect the three-port valve body **160** allows for a constant purge of the valve chamber **161**. Those of skill in the art will then appreciate that there is less particle formation from residual materials remaining in the valve chamber **161** due to the continuous purge.

[0033] Preferably, the distance (i.e. the operating stroke) the valve rod **109** moves between a closed position and an open position is about 0.2 mm or less. This is shorter than the stroke length of 0.5 mm in known electronic valves. A short operating stroke reduces the impact force between the diaphragm **111** and the valve seat **172**. As a consequence, a reduced impact force reduces the chance of degradation of the diaphragm **111** and the valve seat **172**. In addition, a reduced impact force reduces the likelihood of deformation of the valve seat **172** and the resulting likelihood of leakage between the diaphragm **111** and the valve seat **172** in a closed position. Formation of particles along the seat **172** may also develop. Along with a reduced operating stroke, the flow coefficient of the valve assembly **100** preferably remains relatively high. In one preferred embodiment, the operating stroke of the valve rod **109** is about 0.2 mm or less and the Cv constant is between about 0.1 and about 0.13.

[0034] The biasing force of the spring **115** may be adjusted to reduce the force applied to the valve rod **109** when the diaphragm **111** moves from an open position to a closed position. Thus, the velocity of the valve rod **109** and the impact force between the diaphragm **111** and the valve seat **172** is reduced. In a countervailing consideration, the force of the spring **115** should be large enough to ensure an adequate seal between the diaphragm **111** and the valve seat **172** in a closed position. Preferably, the leakage across the diaphragm **111** and the valve seat 170 is about 1×10^{-9} sccm or less when the seal is tested against vacuum to atmosphere.

[0035] The diaphragm **111** preferably comprises at least two separate diaphragm members. In **Figure 1**, separate top **111a** and bottom **111b** diaphragms are shown. In one embodiment, the bottom diaphragm **111b** is closest to the valve seat **172** and has a thickness that is at least 25% greater than the thickness of the top diaphragm **111a**. By way of example, the top diaphragm **111a** has a thickness of about 0.1 mm, while the bottom diaphragm **111b** has a thickness of about 0.125 mm. It has been observed that a thicker bottom diaphragm **111b** reduces the degradation thereof and thus, increases the lifetime of the valve assembly **100**. Preferably, the lifetime of the valve assembly **100** is at least about 5×10^6 cycles or more.

[0036] The valve seat **172** is preferably fabricated as a separate piece from the valve body **160**. Alternatively, the valve seat **172** may be an integral piece with the valve body **160**. Whether a separate piece or an integral piece with the valve body **160**, the valve seat **172** is preferably made of a chemically resistant material which does not react with the reactant provided through the reactant inlet **162**. The valve seat **172** is preferably made of polychlorotriflouroethylene (PCTFE) or polytetrafluoroethylene (PTFE) which have the qualities of being 1) hard enough to resist deformation from the impact by the diaphragm **111**, 2) soft enough to reduce degradation of the diaphragm **111**, and 3) resistant to reaction with reactants (i.e. B_2H_6, $TiCl_4$, NH_3, WF_6, and/or other reactants) at high temperatures (i.e. about 100° C and higher). In less preferred embodiments, possible materials for the valve seat **172** include polyimide (PI), perfluoroalkoxy (PFA), other polymers, metals, and metal alloys. In certain embodiments, depending on the reactant provided therethough, the valve body **160** is heated to a temperature of about 90°C or more, or even 120°C or more, to prevent condensation of the reactant on the diaphragm **111** or other valve assembly **100** components during use.

[0037] The surface area of the valve seat **172** is preferably increased in order to disperse the impact force between the diaphragm **111** and the valve seat **172**. Increasing the surface area of the valve seat **172** may include increasing the internal diameter and/or the width of the diameter **111**.

[0038] Referring now to **Figure 2**, **Figure 2** presents a cross-sectional view of one embodiment of an electronically controlled valve assembly **100'**. In this alternate arrangement, the assembly **100'** employs a two-port valve body **160'** rather than the three-port body of **Figure 1**. The electronically controlled valve assembly **100'** comprising a two-port valve body **160'** is similar to the valve assembly **100** including a three-port valve body **160** of **Figure 1**. As a consequence, like numerals have been used where appropriate.

[0039] The two-port valve body **160'** of the valve assembly **100'** includes a valve chamber **161'** in fluid communication with two ports -- a reactant inlet **162'** and an outlet **166'**. In an open position, the diaphragm **111** is off of the valve seat **172'** to allow the in-flow of a reactant from the reactant inlet **162'**. The reactant gas flows into the valve chamber **161'**, through the outlet **166'**, and into the substrate processing chamber body as described with **Figure 1** above. In a closed position, the diaphragm **111** is in contact with the valve seat **172** to prevent the in-flow of a reactant from the reactant inlet **162'**. The use of a two-port valve body **160'** allows for a reduced amount of reactants to be used since the reactants are not diluted by a constant flow of purge gas in comparison to a three-port valve body.

[0040] **Figure 3** is a graph of the response time **310** of the piston **170'** when moved between its closed position and its open position. The term "response time" as used herein is defined as the time to move the piston **170'** (and connected diaphragm **111**) of the valve assembly **100** or **100'** move from an open position to a closed position or from a closed position to an open position. The response time to move the piston **170'** from an open position to a closed position, and the response time to move the piston **170'** from a closed position to an open position may be the same or may be different, but are preferably approximately the same. Preferably, the valve assembly **100** has a response time of about 20 msec or less, and more preferably 5 msec or less.

[0041] Reducing the response time of a valve assembly **100** permits more cycles of pulses of reactants to be provided over time. Therefore, throughput of processing substrates is increased. However, the valve assembly **100** can be operated to any desired pulse time **320**. The term “pulse time” as used herein is defined as the time to move the piston **170’**/diaphragm **111** from a fully closed position to a fully open position and back to fully closed position. The valve assembly **100**, **100’** may be operated to provide pulse times of about 200 msec or less, about 100 msec or less, and even about 50 msec or less.

[0042] **Figure 4** provides a graph in which the PLC **182** is configured to control the driver **180**. A comparison is made between the current level applied by the driver **180** and the position of the diaphragm **111**. According to the graph, both the presence of current and the position of the diaphragm **111** are shown as a function of time.

[0043] In the arrangement shown in **Figure 4**, the valve assembly **100** is biased in its closed position. This means that when no current is applied through the connector **101**, the piston **170’** is in its closed position. When current is delivered through the connector **101**, the piston **170’** moves to its open position. When the piston **170’** is moved from an open position to a closed position, the current at time **402** is shut off to the solenoid coil **102** so that the spring **115** will move the diaphragm **111** towards the valve seat **172, 172’**. Before the diaphragm **111** reaches the valve seat **172, 172’**, a short pulse of current **414** is applied at time **404** to the solenoid coil **102** to reduce the velocity of the piston **170’**. A reduction in the velocity of the piston **170’** results in a reduced impact force of the diaphragm **111** against the valve seat **172, 172’**. However, if too large a pulse of current is applied, the solenoid coil **102** will cause the diaphragm **111** to move away from the valve seat **172, 172’**. Because the elastic force of the spring **115** does not stay constant over time, and because of the difficulty of timing a pulse of current for valves having a short response time, the pulse of current **414** is turned off prior to the diaphragm

111 contacting the valve seat **172, 172'**. This ensures adequate sealing between the diaphragm **111** and the valve seat **172, 172'**. Thus, a current **414** acts as a dynamic break of the diaphragm **111** of **Figures 1** and **2**.

[0044] The valve assembly **100, 100'** may optionally include diaphragm position indicators to directly or indirectly determine the position of the diaphragm **111**. This ensures that the diaphragm **111** is moving between an open position and a closed position so that no pulses of reactants or cycles are missed. In one embodiment, the current output of the driver **180** may be measured to determine if there is a short in the line **101** between the driver **180** and the solenoid coil **102**. In another embodiment, a gauge **190** (seen in **Figures 1** and **2**) may measure the pressure in the gas line between the reactant source and the reactant inlet **162, 162'**. The gauge **190** provides a way of determining whether pressure in the gas line is building up when the diaphragm **111** is in a closed position and whether the pressure in the gas line is being released when the diaphragm **111** is an open position. In still another embodiment, a mechanical amplifier may use mechanical means of determining the position of the diaphragm **111**. In yet another embodiment, a sensor, such as a magnetic sensor or a laser, may be used to determine the position of diaphragm **111**.

[0045] The valve assembly **100, 100'** of **Figures 1** and **2** may be used with any suitable substrate processing chamber to provide pulses of reactants thereto. Preferably, the valve assembly **100, 100'** is surface-mounted to the chamber. Alternatively, the valve assembly **100, 100'** may be coupled to the chamber through a gas line.

[0046] In one example, the valve assembly **100, 100'** may be used with the chamber lid described in U.S. Patent Application Serial No. 10/032,293 entitled "Chamber Hardware Design For Titanium Nitride Atomic Layer Deposition," filed on December 21, 2001, which is incorporated by reference in its entirety to the extent not inconsistent with the present disclosure. The valve assembly **100, 100'** may also be used with the chamber lid as described in U.S. Patent Application Serial No. 10/016,300 entitled "Lid Assembly For A Processing System To Facilitate Sequential Deposition Techniques," filed on December 12, 2001, which claims priority to U.S.

Provisional Application Serial No. 60/305,970 filed on July 16, 2001, which are both incorporated by reference in their entirety to the extent not inconsistent with the present disclosure. The valve assembly **100, 100'** may also be used with the apparatus disclosed in U.S. Patent Application Serial No. 10/032,284 entitled "Gas Delivery Apparatus and Method for Atomic Layer Deposition," filed on December 21, 2001, which claims benefit of United States Provisional Patent Application Serial Number 60/346,086, entitled "Method and Apparatus for ALD Deposition," filed October 26, 2001, which are both incorporated by reference in their entirety to the extent not inconsistent with the present disclosure. The valve assembly **100, 100'** may also be used with other suitable chambers.

[0047] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims:

1. An electronically controlled valve assembly, comprising:

a valve body having a valve seat, and at least one gas inlet and one gas outlet below the seat;

a piston movable within the valve body above the valve seat between an open position and a closed position, the piston being configured to seal the at least one gas inlet when the piston is moved to its closed position;

a solenoid coil for generating a magnetic field; and

a magnetic member, the magnetic member and the solenoid coil moving relatively away from each other when the solenoid coil is electromagnetically induced, such relative movement moving the piston between its open and closed positions.

2. The valve assembly of claim 1, wherein the gas outlet is in fluid communication with a substrate processing chamber.

3. The valve assembly of claim 2, wherein:

the position of the solenoid coil is fixed relative to the piston; and

the magnetic member mechanically acts against the piston to move the piston.

4. The valve assembly of claim 3, wherein the magnetic member is attached to the piston.

5. The valve assembly of claim 2, wherein:

the position of the solenoid coil is fixed relative to the piston; and

the magnetic member magnetically acts against the piston to move the piston.

6. The valve assembly of claim 2, wherein:

the position of the magnetic member is fixed relative to the piston; and

the solenoid coil mechanically acts against the piston to move the piston.

7. The valve assembly of claim 6, wherein the solenoid coil is attached to the piston.

8. The valve assembly of claim 2, wherein:

the position of the magnetic member is fixed relative to the piston; and

the solenoid coil magnetically acts against the piston to move the piston.

9. The valve assembly of claim 2, wherein the at least one gas inlet defines a reactant inlet and a purge gas inlet.

10. The valve assembly of claim 9, wherein the valve seat is configured to permit fluid communication between the purge gas inlet and the at least one outlet even when the piston is in its closed position.

11. The valve assembly of claim 2, wherein the piston comprises an elongated shaft, and a diaphragm at an end of the shaft for sealing against the at least one gas inlet when the piston is in its closed position.

12. The valve assembly of claim 11, wherein:

the piston further comprises an upper shaft, and a lower valve rod coupled to the upper shaft; and

the diaphragm is disposed at an end of the valve rod opposite the upper shaft.

13. The valve assembly of claim 11, wherein the diaphragm comprises:

an upper diaphragm member coupled to the shaft; and

a lower diaphragm member for sealing against the at least one gas inlet when the piston is in its closed position.

14. The valve assembly of claim 13, wherein the lower diaphragm has a thickness at least approximately 25% greater than a thickness of the upper diaphragm.

15. The valve assembly of claim 2, wherein the piston has a stroke length of about 0.2 mm.

16. The valve assembly of claim 2, wherein the valve seat is fabricated from a material selected from the group including PCTFE, PTFE, and combinations thereof.

17. The valve assembly of claim 12, further comprising a diaphragm position indicator.

18. The valve assembly of claim 2, wherein the solenoid coil is magnetically induced when it receives current through a control line.

19. The valve assembly of claim 2, wherein current is generated to the solenoid coil by a power driver.

20. The valve assembly of claim 19, wherein the power driver delivers current to the solenoid coil in response to signals from a programmable logic controller.

21. The valve assembly of claim 20, wherein the programmable logic controller is controlled by a main controller.

22. An electronically controlled valve assembly, comprising:

a valve body having a valve seat, and a reactant inlet and a gas outlet below the seat, the gas inlet being in fluid communication with a reactant source, and the gas outlet being in fluid communication with a substrate processing chamber;

a piston movable within the valve body above the valve seat between an open position and a closed position;

a diaphragm disposed at an end of the piston, the diaphragm being configured to seal the at least one gas inlet when the piston is moved to its closed position;

a biasing spring acting on the piston and connected diaphragm;

a solenoid coil for generating a magnetic field; and a magnetic member, the magnetic member and the solenoid coil moving relatively away from each other when the solenoid coil is electromagnetically induced, such relative movement selectively moving the piston between its open and closed positions.

23. The valve assembly of claim 22, wherein the piston and connected diaphragm are biased by the spring in the closed position.

24. The valve assembly of claim 22, wherein:

the position of the solenoid coil is fixed relative to the piston; and

the magnetic member mechanically acts against the piston to move the piston.

25. The valve assembly of claim 22, wherein the piston and connected diaphragm are biased by the spring in the open position.

26. The valve assembly of claim 22, wherein the piston has a stroke length of about 0.2 mm.

27. A method of injecting a reactant into a substrate processing chamber, comprising the steps of:

placing a reactant gas source in fluid communication with an electronically controlled valve assembly, the valve assembly comprising:

a valve body having a valve seat, a reactant inlet and a gas outlet,

a piston movable within the valve body above the valve seat between an open position and a closed position, the piston being configured to seal the reactant inlet when the piston is moved to its closed position,

a solenoid coil for generating a magnetic field, and

a magnetic member, the magnetic member and the solenoid coil moving relatively away from each other when the solenoid coil is electromagnetically induced, such relative movement selectively moving the piston between its open and closed positions; and directing a current to the solenoid coil to magnetically induce the coil, causing the piston to move relative to the valve seat.

28. The method of claim 27, wherein the step of directing a current to the solenoid coil causes the piston to move off of the valve seat, allowing reactant gas to move through the valve seat and the gas outlet.

29. The method of claim 27, wherein the step of directing a current to the solenoid coil causes the piston to move onto the valve seat, preventing reactant gas from flowing through the valve seat and the gas outlet.

30. The method of claim 27, further comprising the step of:

discontinuing the directing of current to the solenoid coil, causing the piston to seal against the valve seat, and preventing reactant gas from flowing through the valve seat and the gas outlet.

31. The method of claim 27, wherein:

the position of the solenoid coil is fixed relative to the valve body; and

the magnetic member mechanically acts against the piston to move the piston.

32. The method of claim 31, wherein the magnetic member is attached to the piston.

33. The method of claim 27, wherein:

the position of the solenoid coil is fixed relative to the valve body; and

the magnetic member magnetically acts against the piston to move the piston.

34. The method of claim 27, wherein:

the position of the magnetic member is fixed relative to the valve body; and

the solenoid coil mechanically acts against the piston to move the piston.

35. The method of claim 34, wherein the solenoid coil is attached to the piston.

36. The method of claim 27, wherein:
the position of the magnetic member is fixed relative to the valve body; and
the solenoid coil magnetically acts against the piston to move the piston.

37. The method of claim 27, wherein:
the piston further comprises an upper shaft, and a lower valve rod coupled to the upper shaft; and
the diaphragm is disposed at an end of the valve rod opposite the upper shaft.

38. The valve assembly of claim 37, wherein the diaphragm comprises:
an upper diaphragm member coupled to the shaft; and
a lower diaphragm member for sealing against the at least one gas inlet when the piston is in its closed position.

39. The valve assembly of claim 38, wherein the lower diaphragm has a thickness at least approximately 25% greater than a thickness of the upper diaphragm.

40. The valve assembly of claim 38, wherein the piston has a stroke length of about 0.2 mm.

41. The valve assembly of claim 38, wherein the valve seat is fabricated from a material selected from the group including PCTFE, PTFE, and combinations thereof.

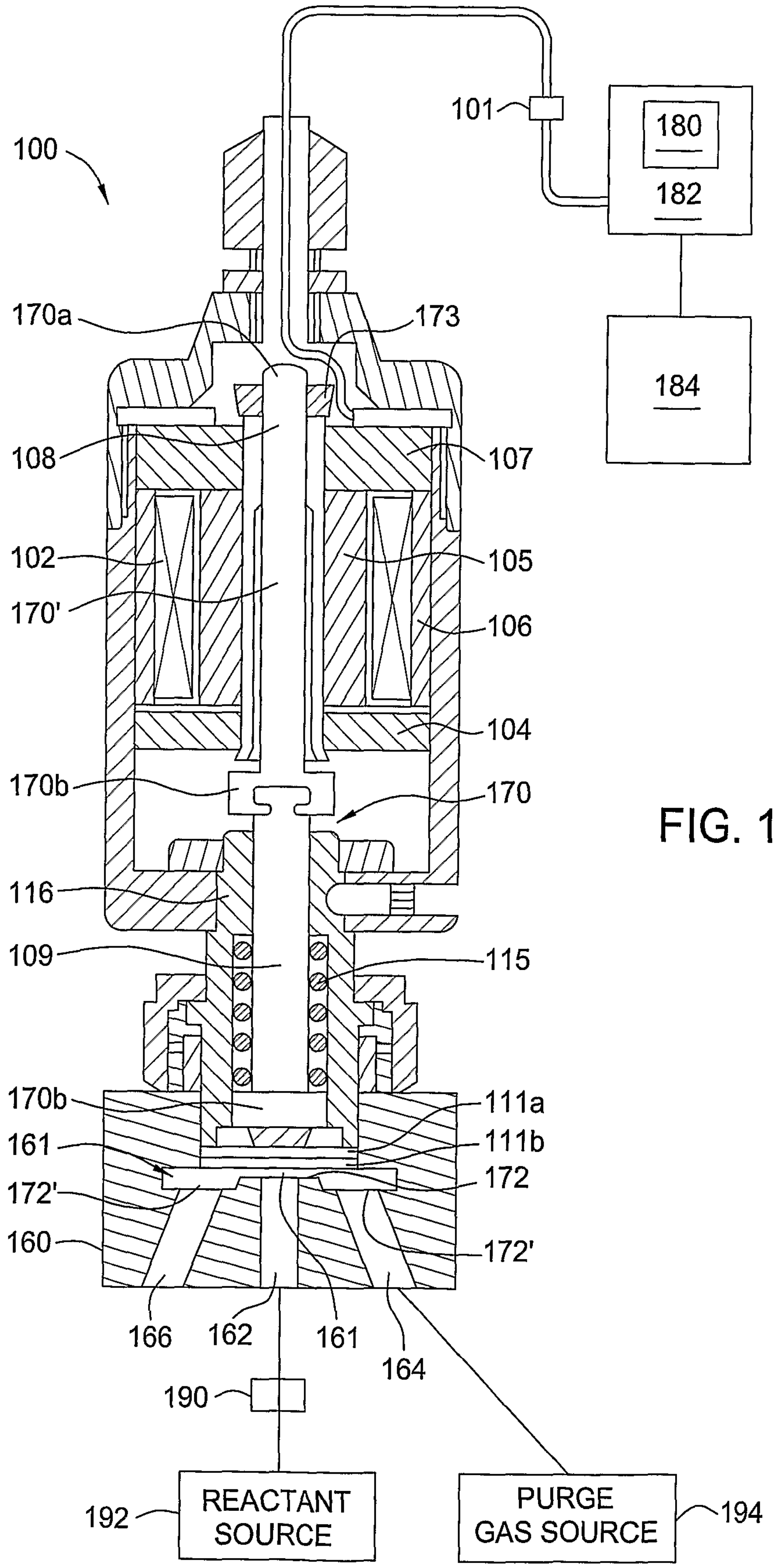

100
101
180
182
184
170a
173
108
107
102
105
170'
106
104
170b
170
116
109
115
170b
111a
161
111b
172'
172
160
172'
166
162
161
164
190
REACTANT SOURCE
192
PURGE GAS SOURCE
194

FIG. 1

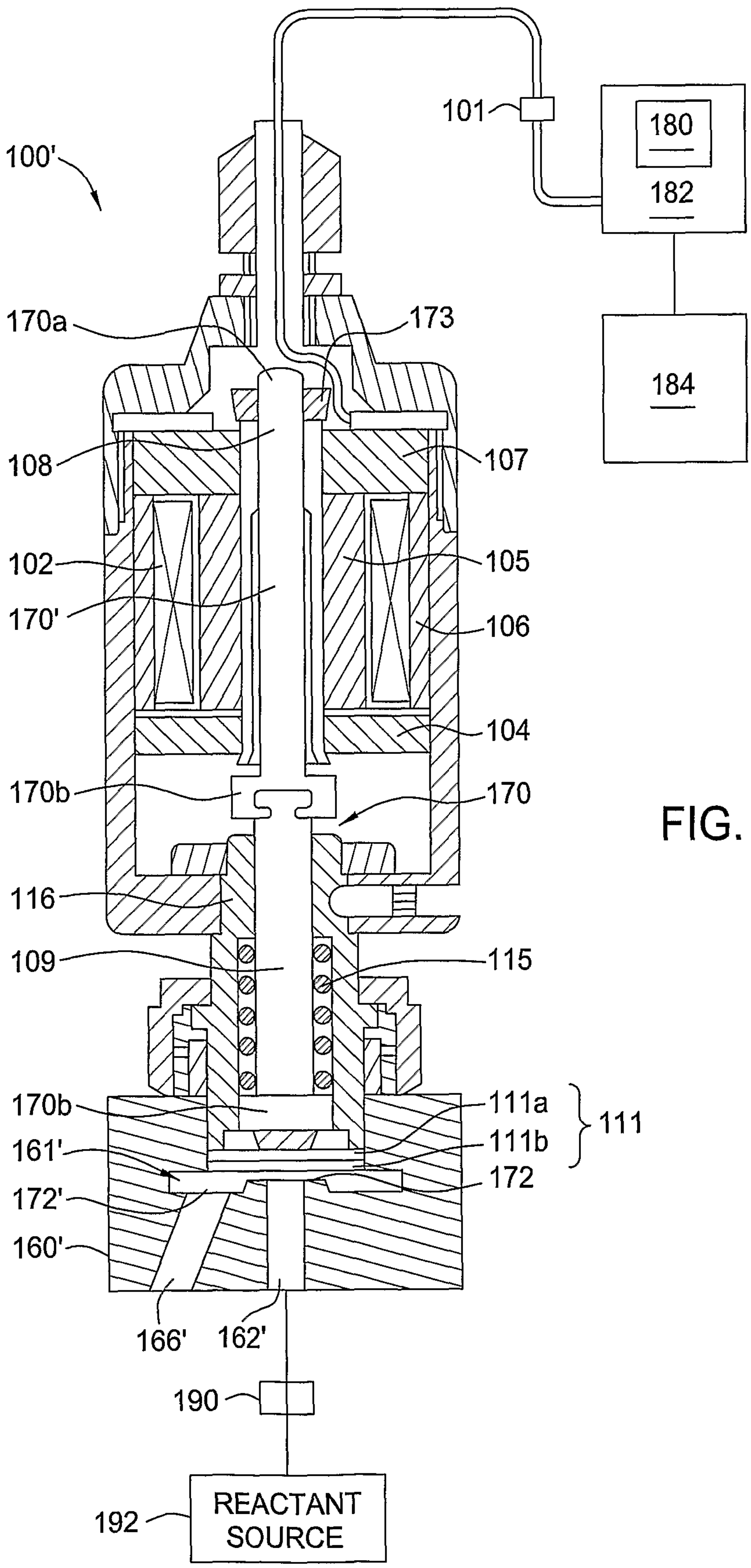

100'
101
180
182
184
170a
173
108
107
102
105
170'
106
104
170b
170
116
109
115
170b
111a
111
161'
111b
172'
172
160'
166'
162'
190
192
REACTANT SOURCE

FIG. 2

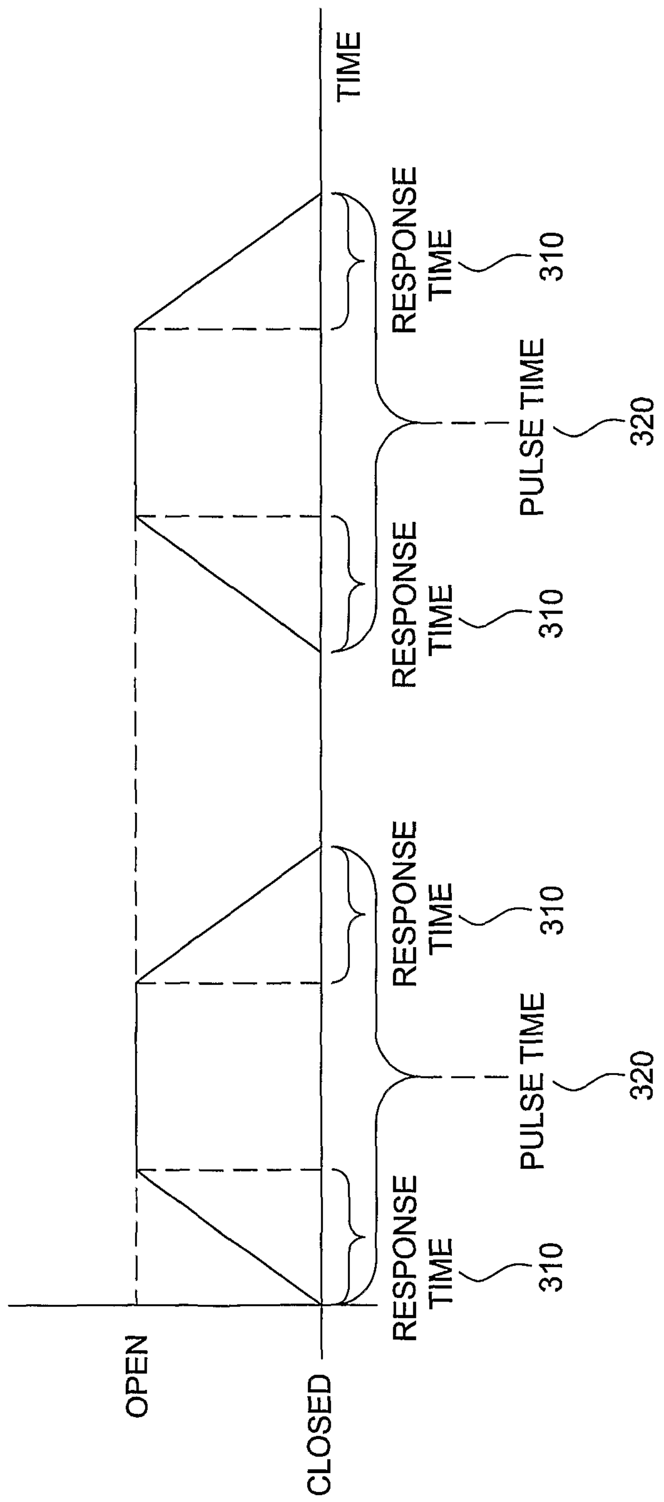

TIME
OPEN
CLOSED
RESPONSE TIME
310
PULSE TIME
320
RESPONSE TIME
310
RESPONSE TIME
310
PULSE TIME
320
RESPONSE TIME
310

FIG. 3

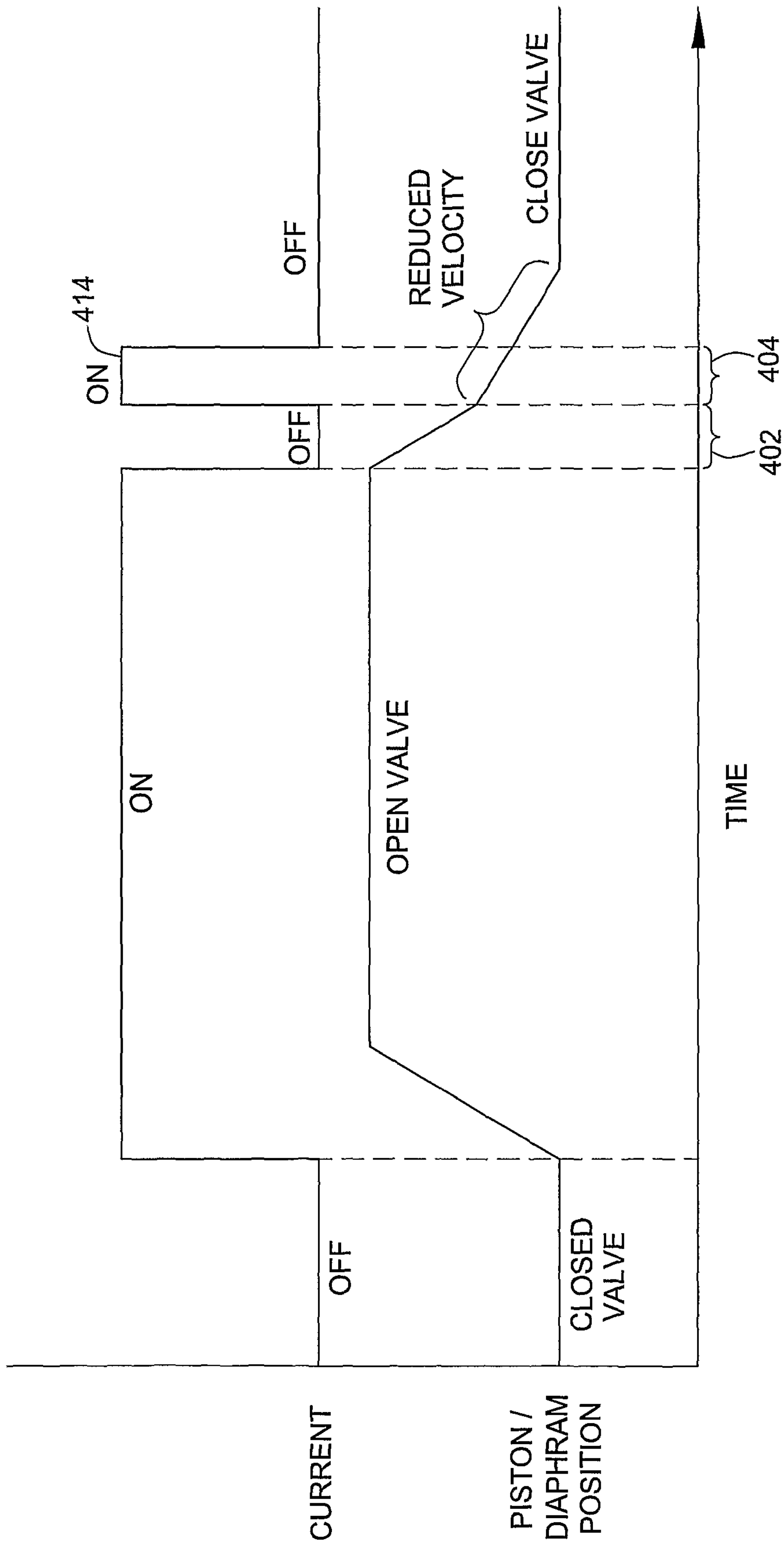

CURRENT
PISTON / DIAPHRAM POSITION
OFF
ON
OFF
ON
OFF
414
CLOSED VALVE
OPEN VALVE
REDUCED VELOCITY
CLOSE VALVE
402
404
TIME

FIG. 4