

PINCH VALVE WITH PRESSURE CONTAINING MEMBER

CROSS REFERENCE TO RELATED APPLICATION

This application is a non-provisional of U.S. Provisional Application No. 60/369,493, April 1, 2002, which is incorporated by reference.

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BACKGROUND OF THE INVENTION**1. FIELD OF THE INVENTION**

The present invention relates generally to fluid flow and control, and more particularly, to a pinch valve having a pressure containing member.

2. DESCRIPTION OF RELATED ART

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A fluid delivery system generally consists of three components: fluid propulsion, flow measurement and control, and a user interface. Many industries such as semiconductor, pharmaceutical, and bio-technology experience fluid delivery problems due to the typically low flow rates, the use of abrasive chemical fluids, the use of corrosive chemical fluids, and the need for contaminant free, accurate, compact, and real-time fluid delivery and/or blending systems.

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For example, Chemical-Mechanical Planarization (CMP) is a critical process in the semiconductor industry that involves a process to flatten the wafer surface of a semiconductor by applying an ultra-pure fluid containing suspended solid particles and a reactive agent between the wafer surface and a polishing pad. In most applications, the polishing pad rotates at a controlled speed against the semiconductor to flatten the surface. Over-polishing the wafer can result in altering or removing critical wafer structures. Conversely, under-polishing of the wafer can result in unacceptable wafers. The polishing rate of the wafer is highly dependent upon the delivery rate of the fluid and the total amount of fluid delivered during a polishing operation.

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Another process used in the semiconductor industry requiring accurate control of fluid flows and a contaminant free environment is the photolithography process. As is known in the art, photolithography is a process that applies a light sensitive polymer, known as resist, or photo resist, to the wafer surface. A photomask containing a pattern of the structures to be fabricated on the wafer surface is placed between the resist covered wafer and a light source. The light reacts with the resist by either weakening or strengthening the resist polymer. After the resist is exposed to light the wafer is developed with the application of fluid chemicals that remove the weakened

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resist. Accurate and repeatable resist delivery is essential to properly transfer the pattern. The resist must be contamination free as any "dirt" on the surface will cause a defect in the final pattern.

A modification of this process applies a host of new liquids to the wafer surface to create films that will become an integral part of the final semiconductor. The primary function of these films is to act as an insulator between electrical conducting wires. A variety of "spin-on" materials are being evaluated with a wide variety of chemical compositions and physical properties. The key difference between the lithography process and the spin-on deposition is that any defect in the film (such as a void, bubble or particle) is now permanently embedded in the structure of the semiconductor and could result in non-functioning devices and a financial loss for the semiconductor producer.

Both of these processes take place in a tool called a "track." The purpose of the track is to apply a precise volume of fluid to the surface of a stationary or slowly spinning wafer. Additional chemical processing steps may be used to convert the liquid to the proper structure. After the liquid application, the wafer rotation speed is rapidly increased and the liquid on the wafer surface is spun off the edge. A very thin, consistent thickness of liquid remains from the center of the wafer to the edge. Some of the variables that affect liquid thickness include the resist or dielectric viscosity, solvent concentration in the resist or dielectric, the amount of resist/dielectric dispensed, speed of dispense, etc.

The track will also provide additional processing steps after liquid application that changes the liquid to a polymer using a bake process that also removes any solvent in the film. The track also controls the environment around the wafer to prevent changes in humidity or temperature and chemical contaminants from affecting the performance of the film. Track system performance is determined by the accuracy and repeatability of liquid delivered to the wafer surface in addition to minimizing defects in the film caused by voids, bubbles and particles.

The fluid control element is thus a critical component of such systems to insure proper delivery of the process fluids. A need exists for an efficient, compact and contaminant free fluid control device to address shortcomings associated with the prior art.

SUMMARY OF THE INVENTION

In one aspect of the invention, a control valve includes an elastomeric flow tube and an actuator having a plunger operatively connected thereto. The plunger is situated adjacent the flow tube and a reference surface is positioned generally opposite the ram such that the elastomeric tube is squeezable between the plunger and the reference surface to control fluid flow through the flow tube. The flow tube material is relatively soft so that it can be compressed between the plunger and reference surface to control the flow. In some instances, the soft flow tube material may have a low pressure rating due to its low strength. A pressure containing member is situated about at least a portion of the flow tube to improve its pressure rating. In exemplary embodiments of the invention, the pressure containing member may comprise, for example, a braided sleeve, rings, or one or more rigid members situated about the flow tube. In one exemplary embodiment, first and second members are sandwiched about the flow tube in a "clamshell" arrangement.

In other aspects of the invention, a mass flow measurement and control device includes an enclosure, a flow measurement device situated in the enclosure and a pinch valve including an elastomeric flow tube in fluid communication with the flow measurement device. The pinch valve has an actuator with a plunger operatively connected thereto. The plunger is situated adjacent the elastomeric tube, and a reference surface positioned generally opposite the plunger so that the elastomeric tube is squeezable between the plunger and the reference surface. A pressure containing member is situated about at least a portion of the elastomeric tube.

The mass flow measurement and control device may further include a controller receiving a measurement output signal from the flow measurement device. The controller provides a control output signal to the pinch valve actuator in response to a setpoint signal and the measurement output signal. In certain exemplary embodiments, the pinch valve is situated in the enclosure. In other embodiments, the pinch valve elastomeric tube and the pressure containing member extend outside the enclosure. The pinch valve elastomeric tube may be positioned downstream or upstream of the flow measurement device.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

Figure 1 is a block diagram schematically illustrating a pinch valve in accordance with an exemplary embodiment of the present invention;

Figure 2 pictorially illustrates a pinch valve including a braided sleeve pressure containing member in accordance with an embodiment of the invention;

5 Figure 3 conceptually illustrates a portion of the pinch valve shown in Figure 3, with a portion of the braided sleeve removed;

Figure 4 pictorially illustrates a pinch valve including rings situated about the pinch tube for pressure retention in accordance with another embodiment of the invention;

10 Figure 5 pictorially illustrates a pinch valve including a clamshell pressure containing member in accordance with another embodiment of the invention;

Figure 6 is a perspective view of one portion of the clamshell pressure containing member shown in Figure 5;

15 Figure 7 shows the valve of Figure 5 with a portion of the clamshell pressure containing member removed; and

Figures 8 and 9 are block diagrams illustrating flow measurement and control devices employing a pinch valve in accordance with an exemplary embodiment of the invention.

20 While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

25 DETAILED DESCRIPTION OF THE INVENTION

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such
30 actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and

time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

A pinch valve 100 in accordance with an embodiment of the present invention is conceptually illustrated in Figure 1. An actuator 122 is situated next to an elastomeric tube 126. A valve plunger 124, which may be in the form of a piston or ram, is moved by the actuator 122 to selectively squeeze or pinch the tube 126 against a reference surface 128, thus varying the size of the opening through which fluid flows 129. The flow tube 126 is made of material that is relatively soft so that it can be compressed between the plunger 124 and the reference surface 128 to control the flow. In some instances, the soft flow tube material may have a low pressure rating due to its low strength. A pressure containing member 130 is situated about at least a portion of the tube 126 to improve the pressure rating of the tube 126.

Many applications, such as those associated with the semiconductor, pharmaceutical, and bio-technology industries, require the flow path (all surfaces wetted by the process fluid) of fluid delivery systems be constructed of high purity, chemically inert/resistant, materials to protect the purity of the chemicals used. Plastics are desirable because the ultra pure chemicals used in the semiconductor wafer fabrication processes can be contaminated if metal ions are leached or removed from metal flow tubes due to a variety of mechanical and chemical processes. Plastic materials are corrosion resistant to a wide range of process materials. High purity grade plastics are thus used in these industries since this generally prevents transferring unwanted ions to the process material. In addition, the smooth surface finish inherent in the manufacturing of a plastic flow tube reduces the ability of bacteria to attach to the tube and contaminate the fluid with organic materials.

In such high purity applications, the tube 126 is preferably made of a high purity elastomer or plastic. A suitable high purity elastomer is silicone (cross-linked polysiloxane) as it is chemically resistant and has the proper chemical properties. Other suitable tubing materials are PVC (polyvinylchloride, Tygon), Polypropylene and Fluorocarbon Rubber (Viton). A variety of fluorinated polymers such as PVDF and PTFE are also suitable. For example, PFA, a mixture including PFA materials, and silicone are suitable materials for the tube 126 in high purity applications. Moreover, in exemplary embodiments of the valve 100, there are no places where stagnant fluid can

collect and no sliding or rubbing parts that could create particles in the fluid, making the disclosed design especially well suited for high purity applications.

The tube's flexibility allows the tubing walls to conform around any trapped particles or imperfections in the walls to provide a tight seal. The flow path is straight through, minimizing pressure drop and turbulence. The fluid contacts only the flow tube 126 preventing wear or corrosion of the other valve parts and preventing contamination of the process fluid in the case of high purity applications, such as semiconductor polishing operations.

Figure 2 shows a pinch valve 200 in accordance with an embodiment of the present invention, in which the pressure containing member comprises a braided sleeve 230 surrounding the flow tube 126. In some embodiments, the braided sleeve surrounds the entire flow tube 126. Figure 3 schematically illustrates portions of a pinch valve 201, in which a portion 232 of the braided sleeve 230 is removed. In the embodiment illustrated in Figure 3, the removed portion 232 of the sleeve 230 is adjacent the valve plunger 124, so that the valve plunger 124 directly contacts the flow tube 126, rather than the pressure containing sleeve 230.

Generally, the braided sleeve 230 does not interfere with operation of the valve 201. Certain materials used for the braided sleeve 230, however, may take a permanent set if the valve plunger 126 is pushed against the sleeve material long enough to permanently deform the material. Such a deformed configuration of the sleeve may cause control problems. This type of deformation may occur, for example, with valves having a normally closed configuration, in which the plunger 126 compresses the flow tube 126 and sleeve 230 for long periods of time. Removing the portion 232 of the sleeve 230 in the illustrated location allows the plunger 126 to directly contact the flow tube 126, while maintaining the pressure containing properties of the braided sleeve 230. The sleeve material can be mechanically cut (scissors, cutters, etc.), thermally cut (to prevent unraveling of the material), etc. to achieve the desired opening geometry. Thus, the sleeve 230 acts as a "holder" for the tube 126. The sleeve 230 also offers pressure containment for the flow tube 126 and maintains an increased pressure rating of the portion of the flow tube 126 contained within the pinch valve body.

Figure 4 illustrates a pinch valve 300 in accordance with another exemplary embodiment of the invention. In the pinch valve 300, the pressure containing member

comprises a plurality of rings 330 situated about the flow tube 126. In a particular embodiment, 1 mm wide polypropylene rings are spaced on the flow tube 126 on either side of the actuator 122.

In other embodiments, the pressure containing member comprises one or more rigid members situated about the flow tube 126. For example, the flow tube 126 may be inserted through a bore defined by such a rigid structure to provide pressure containment. In such an embodiment, the pressure containing member surrounds the flow tube. However, it is not essential that the entire tube be received by the pressure containing member. If more than half of the tube is surrounded, some pressure containment will be realized.

Figure 5 shows a pinch valve 400 in accordance with an exemplary embodiment of the present invention that uses a rigid member including two pieces. The pinch valve 400 includes a “clamshell” pressure containing member 430 that includes upper and lower members 431, 432. Figure 6 illustrates the lower member 432; the upper member 431 is similar. Figure 7 shows the valve 400 with only the upper member 431 of the pressure containing member 430 in place. The upper and lower members 431, 432 each define a groove 440 that generally corresponds to the shape of the flow tube 126, such that when the upper and lower members 431, 432 are sandwiched about the flow tube 126, the grooves 440 receive the flow tube 126 to provide pressure containment.

In the illustrated embodiment, the upper and lower members 431, 432 further define an opening 442 that receives the lower portion of the actuator 122. The upper and lower members 431, 432 are held together by any appropriate means to form the pressure containing member 430. In tests conducted on one embodiment using 0.25 inch silicone tubing for the pinch tube 126 with the clamshell pressure containing member 430, the pinch tube 126 did not burst until the pressure exceeded 200 psig. As noted above, the two-piece clamshell arrangement is exemplary; the rigid pressure containing member may comprise a single member, or several members.

The actuation of known pinch valves is usually bi-stable – on and off. Some known pinch valves have a manual actuator with a multi-turn handle, but this type of valve would not be conducive to closed loop flow control. Other pinch valves are used for dispensing applications in batch processes, in which the amount of material

dispensed is controlled by the time that the valve is on. This does not allow dynamically controlling the flow rate in a continuous manner.

A valve that has only two states can be controlled by applying varying current or voltage to the valve actuator. In one embodiment, pulse width modulation (PWM) is used to control the valve. PWM is achieved by generating a square wave signal at a frequency above the valve's mechanical response frequency. The duty cycle of the signal is varied to determine the appropriate voltage or current sent to the device. For example, if the PWM signal operates between 0-12 volts, 0% duty cycle = 0 volts, 50% duty cycle = 6 volts, and 100% duty cycle = 12 volts. The "averaging" takes place because the signal is at a frequency above the valve's mechanical response frequency. The position of the valve is based on the average current that is supplied. The resulting supply voltage is proportional to the pulse width of the signal.

If the signal frequency is too low, the valve will have time to respond completely to on and off signals creating a pulsed flow output, which is generally not desirable. A typical pinch valve actuator is a solenoid, which has a spring element with a preload adjustment that determines the current required to close the solenoid. Adjusting the pre-load on the valve spring can improve the valve's control range. In other implementations, the solenoid plunger element is replaced with a spring-suspended plunger. The spring-suspended plunger minimizes the non-linear valve response due to friction, which minimizes the hysteresis and dead band common in available solenoid-actuated pinch valves.

An alternative approach to the PWM-controlled solenoid is to use a stepper motor actuator, which translates a controlled, deterministic angular rotation to a linear ram drive by a worm gear type arrangement. Stepper controllers can be designed to produce a specific number of steps proportional to an analog signal input. Backlash, and thus valve hysteresis can be minimized by any number of appropriate worm gear designs that minimize backlash. A stepper motor generally provides immunity to temperature and pressure fluctuations, which may cause changes in the pinch tubing. A stepper motor is a means to control position, so the stepper is immune changes in the pinch tubing. With a pinch valve, the pinch tube is an integral part of the system – current is applied to the valve actuator, which applies force to the pinch tube, which pinches the tube. If the tube properties change due to temperature or pressure, the amount the tube closes, and thus the flow rate with a solenoid, changes. Moreover, a

stepper actuator can remain at the last position to provide fast response to achieving setpoint at the start of a fluid delivery cycle.

Figures 8 and 9 schematically illustrate a flow measurement and control device 110 employing a pinch valve 100 in accordance with the present invention. The measurement and control device 110 includes an enclosure 101 having a fluid inlet and outlet 102, 103. A flow measurement device 112 is situated in the enclosure 101. In an exemplary embodiment, the flow measurement device 112 comprises a Coriolis mass flowmeter.

In high-purity applications, the flowmeter 112 preferably has a flow-tube made of a high-purity plastic material to prevent contamination of the process fluid caused by transferring unwanted (e.g. metal) ions to the process material. Suitable high purity plastic materials include PFA, PVDF and PTFE. As noted herein above, the pinch valve 100 may also include components made of a high purity plastic material to prevent transferring ions to the process material. In the block diagram of Figure 8, the valve 100 is shown as being situated completely within the enclosure 101. In some embodiments, portions of the valve, or the entire valve, are attached to an outside surface of the enclosure 101, as in the embodiments shown in Figures 2, 4 and 5.

A controller 114 receives a setpoint signal and an output signal from the flowmeter 112. The controller 114 conditions and processes the signal from the flow meter and outputs a control signal to the pinch valve 100 to vary the flow rate of the process material based on a comparison of the setpoint and measured flow rate. The setpoint input to the controller 114 is typically an electronic signal such as a 0-5V, 4-20mA signal or a digital signal. A pneumatic setpoint interface could also be used. A suitable setpoint generator is a model P48 process controller available from Red Lion Controls of York, Pennsylvania.

The controller 114 may also have a feature commonly known as valve override, where an additional signal is sent to the controller 114. This override signal causes the controller 114 to ignore the setpoint and fully open or close the valve 100. This feature is often used for shutting the flow off or purging the system. In Figure 8, the controller 114 is shown as being positioned inside the enclosure 101, providing a completely integrated flow control system. In other embodiments, however, the controller 114 is external to the enclosure 101.

The pinch valve 100 regulates the flow through the device 110, and it also provides a buffer against changes in line pressure. The valve 100 can be positioned either upstream of the mass flowmeter 112 as shown in Figure 8, or downstream as in the embodiment shown in Figure 9. Generally, it is preferable to have the valve 100 on the side that will see the largest pressure variations during use. This helps shelter the flow meter 112 from pressure changes and fluctuations.

The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.

CLAIMS**WHAT IS CLAIMED IS:**

1. A control valve, comprising:
an elastomeric flow tube;
5 an actuator;
a plunger operatively connected the actuator, the plunger being situated adjacent
the flow tube;
a reference surface positioned generally opposite the plunger such that the
elastomeric tube is squeezable between the plunger and the reference
10 surface to control fluid flow through the flow tube; and
a pressure containing member situated about at least a portion of the flow tube.
2. The control valve of claim 1, wherein the pressure containing member
comprises a braided sleeve.
3. The control valve of claim 1, wherein the pressure containing member
15 comprises a plurality of rings.
4. The control valve of claim 1, wherein the pressure containing member
comprises a rigid member receiving at least a portion of the flow tube.
5. The control valve of claim 4, wherein the rigid member comprises first and
second members sandwiched about the flow tube.
- 20 6. A mass flow measurement and control device, comprising:
an enclosure;
a flow measurement device situated in the enclosure; and
a pinch valve including an elastomeric flow tube in fluid communication with the
flow measurement device, an actuator having a plunger operatively
25 connected thereto situated adjacent the elastomeric tube, and a reference
surface positioned generally opposite the plunger such that the elastomeric
tube is squeezable between the plunger and the reference surface, and a
pressure containing member situated about at least a portion of the
elastomeric tube.

7. The mass flow measurement and control device of claim 6, further comprising a controller receiving a measurement output signal from the flow measurement device, the controller providing a control output signal to the pinch valve actuator in response to a setpoint signal and the measurement output signal.

5 8. The mass flow measurement and control device of claim 6, wherein the pinch valve is situated in the enclosure.

9. The mass flow measurement and control device of claim 6, wherein the pinch valve elastomeric tube and the pressure containing member extend outside the enclosure.

10 10. The mass flow measurement and control device of claim 6, wherein the pinch valve elastomeric tube is positioned downstream of the flow measurement device.

11. The mass flow measurement and control device of claim 6, wherein the pinch valve elastomeric tube is positioned upstream of the flow measurement device.

12. A control valve, comprising:

15 an elastomeric flow tube;

an actuator having a plunger operatively connected thereto situated adjacent the flow tube, and a reference surface positioned generally opposite the ram such that the elastomeric tube is squeezable between the plunger and the reference surface to control fluid flow through the flow tube; and

20 means for pressure containment of the flow tube.