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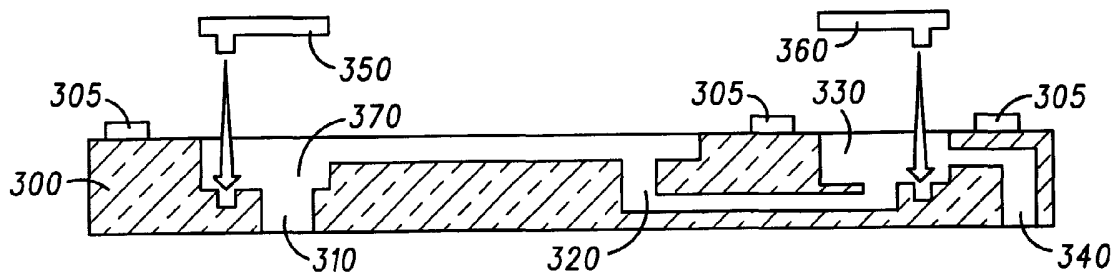
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(54) Title: METHOD OF MAKING PIEZO-DRIVEN MICROPUMP IN LAMINATE SUBSTRATE



(57) Abstract: An exemplary method for making a micropump device is disclosed as providing inter alia a substrate (300), an inlet opening (310), and outlet opening (340), a pump chamber (370) and flapper valves (350, 360). The fluid inlet channel (310) is generally configured to flow a fluid through/around the inlet opening flapper valve (350). The outlet opening flapper valve (360) generally provides means for preventing or otherwise decreasing the incidence of outlet fluid re-entering either the pumping cavity (370) and/or the fluid inlet channel (310). Accordingly, the reduction of backflow generally tends to enhance overall pumping efficiency. Disclosed features and specifications may be variously controlled, adapted or otherwise optionally modified to improve micropump operation in any microfluidic application. Exemplary embodiments of the present invention representatively provide for substantially self-priming gas/liquid micropumps that may be readily integrated with existing portable ceramic technologies for the improvement of device package form factors, weights and other manufacturing and/or device performance metrics.

WO 2004/018876 A1

METHOD OF MAKING PIEZO-DRIVEN MICROPUMP IN LAMINATE SUBSTRATE

FIELD OF INVENTION

[0001] The present invention relates to micropumps, and more particularly, in one representative and exemplary embodiment, to piezoelectrically actuated, high aspect ratio micropumps having integrated check valves for improved performance, efficiency and production cost savings in microfluidic applications.

BACKGROUND

[0002] Development of microfluidic technology has generally been driven by parallel ontological advancements in the commercial electronics industry with the ever-increasing demand for sophisticated devices having reduced part counts, weights, form factors and power consumption while improving or otherwise maintaining overall device performance. In particular, advancement of microfluidic technology has met with some success in the areas of packaging and the development of novel architectures directed to achieving many of these aims at relatively low fabrication cost.

[0003] The development of microfluidic systems, based on for example, multilayer laminate substrates with highly integrated functionality, have been of particular interest. Monolithic substrates formed from laminated ceramic have been generally shown to provide structures that are relatively inert or otherwise stable to most chemical reactions as well as tolerant to high temperatures. Additionally, monolithic substrates typically provide for miniaturization of device components, thereby improving circuit and/or fluidic channel integration density. Potential applications for integrated microfluidic devices include, for example, fluidic management of a variety of microsystems for life science and portable fuel cell applications. One representative application includes the use of ceramic

materials to form micro-channels and/or cavities within a laminate structure to define, for example, a high aspect ratio micropump.

[0004] Conventional pumps and pumping designs have been used in several applications; however, many of these are generally too cumbersome and complex for application with microfluidic systems. For example, existing designs typically employ numerous discrete components externally assembled or otherwise connected together with plumbing and/or component hardware to produce *ad hoc* pumping systems. Consequently, conventional designs have generally not been regarded as suitable for integration with portable ceramic technologies or in various applications requiring, for example, reduced form factor, weight or other desired performance and/or fabrication process metrics. Moreover, previous attempts with integrating microfluidic pumps in laminated substrates have met with considerable difficulties in producing reliable fluidic connections and/or hermetic seals capable of withstanding manufacturing processes and/or operational stress while maintaining or otherwise reducing production costs. Accordingly, despite the efforts of prior art pump designs to miniaturize and more densely integrate components for use in microfluidic systems, there remains a need for high aspect ratio micropumps having integrated check valves suitably adapted for incorporation with, for example, a monolithic device package.

SUMMARY OF THE INVENTION

[0005] In various representative aspects, the present invention provides a system and method for fluid transport in microfluidic systems. A representative design is disclosed as comprising a fluid inlet opening, a fluid outlet opening, a pumping cavity, a reservoir cavity, a check valve substantially enclosed within each of the cavities, and means for moving fluid through the device. An integrated high aspect ratio micropump, in accordance with one embodiment of the

present invention, may be formed utilizing multilayer ceramic technology in which check valves are integrated into a laminated ceramic structure; however, the disclosed system and method may be readily and more generally adapted for use in any fluid transport system. For example, the present invention may embody a device and/or method for providing integrated pumping and/or valving systems for use in fuel cell fuel delivery and/or partitioning applications.

- [0006] One representative advantage of the present invention would allow for improved process control and manufacturing of integrated micropump systems at substantially lower cost. Additional advantages of the present invention will be set forth in the Detailed Description which follows and may be obvious from the Detailed Description or may be learned by practice of exemplary embodiments of the invention. Still other advantages of the invention may be realized by means of any of the instrumentalities, methods or combinations particularly pointed out in the Claims.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0007] Representative elements, operational features, applications and/or advantages of the present invention reside *inter alia* in the details of construction and operation as more fully hereafter depicted, described and claimed – reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout. Other elements, operational features, applications and/or advantages will become apparent to skilled artisans in light of certain exemplary embodiments recited in the detailed description, wherein:
- [0008] FIG. 1 representatively depicts a cross-section, elevation view of a package substrate in accordance with an exemplary embodiment of the present invention;

- [0009] FIG. 2 representatively illustrates one exemplary method for depositing check valves within the package substrate depicted in FIG. 1; and
- [0010] FIG. 3 representatively depicts a cross-section, elevation view of an assembled and substantially sealed micropump device package in accordance with another embodiment of the present invention.
- [0011] Those skilled in the art will appreciate that elements in the Figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the Figures may be exaggerated relative to other elements to help improve understanding of various embodiments of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

- [0012] The following descriptions are of exemplary embodiments of the invention and the inventors' conceptions of the best mode and are not intended to limit the scope, applicability or configuration of the invention in any way. Rather, the following description is intended to provide convenient illustrations for implementing various embodiments of the invention. As will become apparent, changes may be made in the function and/or arrangement of any of the elements described in the disclosed exemplary embodiments without departing from the spirit and scope of the invention.
- [0013] Various representative implementations of the present invention may be applied to any system and/or method for fluid transport. As used herein, the terms "fluid", "fluidic" and/or any contextual, variational or combinative referent thereof, are generally intended to include anything that may be regarded as at least being susceptible to characterization as generally referring to a gas, a liquid, a plasma and/or any matter, substance or combination of compounds substantially not in a solid or otherwise effectively immobile condensed phase. As used herein, the terms "inlet" and "outlet" are

generally not used interchangeably. For example, "inlet" may generally be understood to comprise any cross-sectional area or component feature of a device, the flux through which tends to translate fluid from a volume element substantially external to the device to a volume element substantially internal to the device; whereas "outlet" may be generally understood as referring to any cross-sectional area or component feature of a device, the flux through which tends to translate fluid from a volume element substantially internal to the device to a volume element substantially external to the device. On the other hand, as used herein, the terms "liquid" and "gas" may generally be used interchangeably and may also be understood to comprise, in generic application, any fluid and/or any translationally mobile phase of matter. As used herein, the term "purged", as well as any contextual or combinative referent or variant thereof, is generally intended to include any method, technique or process for moving a volume element of fluid through the outlet of a device so as to dispose or otherwise positionally locate the "purged" volume element external to the device. Additionally, as used herein, the terms "valve" and "valving", as well as any contextual or combinative referents or variants thereof, are generally intended to include any method, technique, process, apparatus, device and/or system suitably adapted to control, affect or otherwise parameterize fluid flow scalar quantities (*e.g.*, volume, density, viscosity, *etc.*) and/or fluid flow vector quantities (*i.e.*, direction, velocity, acceleration, jerk, *etc.*). Additionally, as used herein, the terms "pump" and "pumping", or any contextual or combinative referents or variants thereof, are generally intended to include any method, technique, process, apparatus, device and/or system suitably adapted to flow or otherwise translate a fluid volume element from a first location to a second location.

- [0014] A detailed description of an exemplary application, namely a system and method for making a micropump in a laminar device package is provided as a specific enabling disclosure that may be readily generalized by skilled artisans to any application of the disclosed system and method for microfluidic transport in accordance with various embodiments of the present invention. Moreover, skilled artisans will appreciate that the principles of the present invention may be employed to ascertain and/or realize any number of other benefits associated with fluid transport such as, but not limited to: improvement of pumping efficiency; reduction of device weight; reduction of device form factor; improved sample loading in microfluidic assays; improvement in sample throughput; sample multiplexing and/or parallel sample processing; integration with micro-array techniques and/or systems; microfluidic sample transport; pumping of fuel and/or fuel components in a fuel cell system and/or device; and any other applications now known or hereafter developed or otherwise described in the art.
- [0015] In one representative application, in accordance with an exemplary embodiment of the present invention, a laminar micropump system, as generally depicted in FIG. 3, is disclosed. The system generally includes at least one substantially flexible, or otherwise at least partially deformable, material comprising, for example, a flapper valve 350, 360. The disclosed valving system, in certain representative embodiments, may include features to control the effective magnitude of cross-sectional area presented for fluid acceptance in order to at least partially control or otherwise parameterize fluid flux through said inlet opening 310 and/or outlet opening 340. For example, inlet opening 310 and/or outlet opening 340 may comprise a taper, a flare, a constriction, a plurality of corrugations, a bend, a pinch, an oblique plane of fluid acceptance (e.g., wherein inlet opening 310 and/or outlet opening 340 facial

alignment generally may be other than normal to the instantaneous vector of fluid flow) or such other means, features and/or methods now known, subsequently developed or otherwise hereafter described in the art.

[0016] The operation of flapper valves **350**, **360** generally provide passive means for substantially preventing or otherwise controlling or restricting the backflow of purged outlet fluid into reservoir chamber **330** and/or pumping chamber **370**. For example, outlet flapper valve **360** generally permits fluid flow when the flow vector (*e.g.*, the direction of fluid pressure; also termed the “fluid transport gradient”) corresponds to translation of fluid volume elements away from inlet opening **310** through fluidic channels **320** toward outlet opening **340**. Additionally, outlet flapper valve **360**, in accordance with representative aspects of the present invention, conjunctively provides for effective prevention of fluid flow to outlet opening **340** when the instantaneous fluid transport gradient corresponds to translation of fluid volume elements away from outlet opening **340** through fluidic channels **320** toward inlet opening **310** (*e.g.*, “backflow”). In an alternative exemplary embodiment, reservoir chamber **330** and/or pumping chamber **370** may further or alternatively comprise a mixing chamber, a reaction chamber and/or a fuel reformer chamber (in the case of application of the present invention, for example, to fuel cell systems).

[0017] One exemplary implementation of the present invention may be manufactured from the substrate representatively illustrated in FIG. **1**, wherein a laminar substrate **300** is provided for the fabrication of a piezo-driven micropump. Outlet opening **310** is suitably configured to provide a path for fluid transport to pumping chamber **370**. Fluidic channel **320** provides fluidic communication between pumping chamber **370** and reservoir chamber **330**. Reservoir chamber **330** is generally configured to provide effective fluidic

communication to outlet opening **340**. Skilled artisans, however, will appreciate that other channel configurations and/or circuit geometries may be employed in order to define *inter alia* various fluidic transport paths, for example, in a laminar substrate in accordance with various other embodiments of the present invention.

[0018] In one representative embodiment, openings for disposing flapper valves **350**, **360** are defined in substrate **300** such that flapper valves **350**, **360** may be suitably deposited in pumping chamber **370** and reservoir chamber **330** respectively, from substantially the same surface of substrate **300** presented during fabrication as depicted, for example, in FIG. 2. One exemplary benefit of the disclosed method of same-side device assembly resides in fewer process fabrication/control steps resulting in substantially lowered cost of production.

[0019] Other means for providing substantially passive valving function other than that of a flapper valve include, for example: a slit (*e.g.*, duckbill valve), a plunger, a shuttle, a rotary stop-cock, a one-way flow gate or any other device feature, method or means for substantially passive valving now known, subsequently developed or hereafter described in the art. The same may be alternatively, conjunctively or sequentially used in various embodiments of the present invention. Skilled artisans will appreciate that the term "passive", as it may refer to valving devices and/or function, generally connotes the ability of a valve and/or valve device feature so characterized, to actuate the operation of restriction, constriction and/or dilation of fluid inlet acceptance and/or fluid outlet purging in effective correspondence to the forces nominally inherent to the translation of fluid volume elements through the valve device. That is to say, when the fluid flow is in a first direction, the fluidic forces operate to actuate the valve into a first conformation (*i.e.*,

substantially open); and, when the fluid flow is in a second direction (*e.g.*, for a binary valve, generally given as the “opposite direction”), the fluidic forces operate to actuate the valve into a second conformation (*i.e.*, substantially closed).

[0020] In various exemplary embodiments, flapper valves **350**, **360** may be fabricated from silicone, silicone-based rubber, rubber, metal, metal alloy, polymer or such other materials whether now known or subsequently discovered or otherwise hereafter described in the art. In an exemplary application where passive check valves **350**, **360** comprise flapper valves, as generally depicted, for example, in FIG. 2, the valves may comprise a silicone-based rubber material. Additionally, flapper valves **350**, **360** may optionally comprise means for attachment, such as, for example, an extension tab having a substantially annular retaining ring for securing or otherwise at least partially immobilizing flapper valve **350**, **360** within device package substrate **300**. Various other attachment means and/or packaging features for retaining, localizing or otherwise disposing check valves known in the art may be used as well. For example, the following retaining means may be conjunctively, alternatively or sequentially employed: adhesives, organic epoxies, a mechanical anchor, press-fit clips, solder, clamps, seals, adaptors and/or such other retention, connection or attachment devices, means and/or methods, whether now known or otherwise hereafter described in the art.

[0021] FIG. 3 generally depicts two passive flapper valves **350**, **360** disposed within an exemplary monolithic package substrate **300**. The device package **300** generally comprises an input microfluidic channel **310**, an output microfluidic channel **340** and pump actuator element **380**. In one representative embodiment, pump actuator may comprise a piezoelectric micropump element **380**. In an exemplary embodiment, piezoelectric element **380** may be secured

to the package substrate **300** by, for example, solder **390**. Accordingly, substrate **300** may comprise solder-wettable features **305** that are generally provided to permit secure solder attachment of piezoelectric element **380** and/or cover **375** to substrate **300**. Various other means for attaching piezoelectric element **380** and/or cover **375** to package substrate **300** may include, for example: epoxy, adhesive and/or such other attachment means and/or methods whether now known or hereafter described in the art. In yet another exemplary embodiment of the present invention, piezoelectric element **380** may alternatively be integrated within the package substrate; for example, between ceramic layers in a position substantially internal to the device as the package is built up.

[0022] As electric current is supplied to the package, piezoelectric element **380** operates as a deformable diaphragm membrane whose deformation (*e.g.*, "stroke volume") causes oscillating over- and under-pressures in pump chamber **370**. Pump chamber **370**, in an exemplary embodiment, may be bounded by, for example, two passive check valves **350**, **360**. The pump actuation mechanism **380** need not be limited to piezoelectric actuation, but may alternatively, sequentially or conjunctively be driven by electrostatic or thermopneumatic actuation or such other means and/or methods now known, subsequently derived or otherwise hereafter described in the art.

[0023] During the movement of the diaphragm element (*i.e.*, piezoelectric element **380**) in a direction which tends to enlarge the pump chamber volume, an under-pressure is generated in pump chamber **370** causing fluid to flow through inlet channel **310** in a flow direction which causes pump flapper valve **350** to distend toward piezoelectric element **380** thereby permitting fluid to flow around flapper valve **350** to enter into pump chamber **370**. Since the fluid

transport gradient during the under-pressure stroke is anti-parallel to the fluid flow acceptance conformation of reservoir flapper valve **360**, flapper valve **360** seals so as to at least partial reduce the occurrence of fluid disposed in outlet channel **340** re-entering via fluidic channel **320** into pump chamber **370** (e.g., backflow). Accordingly, this component of the pump cycle is termed the "supply mode" or the "supply stroke".

[0024] In the alternate and next phase of the stroke cycle, the movement of the diaphragm element **380** in a direction which tends to reduce the pump chamber volume causes an over-pressure to be generated in pump chamber **370**, thereby flowing fluid through outlet opening **340** as a result of fluid flowing out of pump chamber **370** into fluidic channel **320** in a flow direction which causes reservoir flapper valve **360** to distend toward, for example, cover plate **375** thereby permitting fluid to flow around flapper valve **370** to enter into reservoir chamber **330** and subsequently into outlet channel **340**. Since the fluid transport gradient during the over-pressure stroke is anti-parallel to the fluid flow acceptance conformation of pump flapper valve **350**, flapper valve **350** seals so as to at least partial reduce the occurrence of fluid disposed in pump chamber **370** from back-flowing into the inlet channel **310**. Accordingly, this component of the pump cycle is termed the "pumping mode" or the "delivery stroke".

[0025] The volume of the pump chamber upon relaxation of the actuation diaphragm is known as the dead volume V_0 and the volume the actuation membrane deflects during a pump cycle generally defines the stroke volume ΔV . The ratio between the stroke volume and dead volume may be used to express the compression ratio ε . Due in part to the relatively small stroke of micro-actuators and the

relatively large dead volume, the compression ratio $\varepsilon = \frac{\Delta V}{V_0}$ is

usually relatively small.

[0026] The pressure cycles (e.g., “pressure waves”) generated from the actuation supply and pump modes typically operate to switch the valves. In the limit of the pump chamber **370** being filled with an ideally incompressible fluid, the pressure waves would ideally propagate from the actuation diaphragm to the valves with no net pressure loss – in which case, the compression ratio is generally not regarded as an important metric of pump performance and/or efficiency. However, where the fluid medium is not ideally incompressible, there exists a compressibility factor $\kappa > 0$ which may be employed to characterize the tendency of a real fluid to dampen the propagation of the actuation pressure wave Δp . If the pressure change Δp falls below a certain value p' (e.g., the threshold pressure differential for actuation of a valve), the pump generally will not properly operate. Accordingly, a minimum condition for operation of any micropump may be expressed as $|\Delta p| \geq |p'|$.

[0027] Given the compressibility κ of a liquid, the pressure change Δp may be calculated (if the volume change ΔV induced by the actuator is known) in accordance with the equation $V_0 + \Delta V = V_0(1 - \kappa\Delta p)$. If this expression is substituted into those previously presented, the compressibility ratio ε for liquid micropumps may be expressed as $\varepsilon_{liquid} \geq \kappa|p'|$. Accordingly, a threshold valve actuation pressure p' of 1kPa in combination with the compression ratio for water κ_{water} ($5 \cdot 10^{-9} \text{ m}^2/\text{N}$) would yield a minimum compression ratio ε_{water} of $5 \cdot 10^{-6}$. In this case, where the stroke volume ΔV is assumed to be 50nl, the dead volume V_0

generally may not exceed 10ml. Skilled artisans, however, will appreciate that the preceding example will generally only hold true where the pump chamber 370 is completely filled with liquid and no degassing and/or bubble occlusion occurs during micropump operation and therefore provides a first-order approximation for the determination of operational parameters and/or design specifications.

- [0028]** In the case of a gas pump, assuming an ideal gas having an adiabatic coefficient of γ (1.4 for air), at atmospheric pressure p_0 and an actuation pressure wave of magnitude Δp , the following expression may be obtained:

$$p_0 V_0^\gamma = (p_0 + \Delta p)(V_0 + \Delta V)^\gamma$$

- [0029]** Accordingly, it may be shown that the criterion for the compression ratio of a gas micropump may be similarly derived as

$$\varepsilon_{gas} \geq \left(\frac{p_0}{p_0 - |p'|} \right)^{\frac{1}{\gamma}} - 1 \text{ and, in the case of isothermal state transitions,}$$

the adiabatic coefficient γ may be taken as equal to unity. For the device previously presented for the micropumping of water (*e.g.*, $p' = 1\text{kPa}$ and $\Delta V = 50\text{nl}$), the dead volume V_0 for the same system adapted for the micropumping of air must generally not exceed $5\mu\text{l}$.

- [0030]** In conventional micropump operation, gas bubbles may often remain in the pump chamber during the priming procedure and/or the liquid may even volatilized in response to temperature changes during operation. In these cases, the expression for the compression ratio of a liquid $\varepsilon_{liquid} \geq \kappa |p'|$ will no longer hold true since the compressibility of the gas bubble is generally much larger than the compressibility of the liquid. Depending on the volume of the gas bubble, the actuation pressure wave will be dampened in an amount that may be calculated if the volume of the gas bubble is substituted for the dead volume in the appropriate equation

presented *vide supra*. If the gas bubble volume becomes so large that the actuation pressure wave falls below the threshold valve actuation pressure, the micropump will fail. Consequently, in the limit of the entire pump chamber volume being filled with a gas, the operational design criteria for liquid self-priming pumps converges to the design criteria for those of gas micropumps.

[0031] Additionally, in practical applications, the design criteria may even need to be more stringent to account for higher-order fluid dynamics. For example, self-priming liquid micropumps must typically suck the liquid meniscus from the inlet **310** into the pump chamber **370**, thereby increasing the threshold critical pressure p' in parity with the surface tension of the meniscus at the juncture between and/or within, for example, the microfluidic channels and the microfluidic valves. Those skilled in the art will recognize that other fluid dynamics and/or parametric contributions may require consideration in the determination of optimal operational specifications for a micropump in accordance with the present invention as they may be employed in a variety of practical applications and/or operating environments. The same shall be regarded as within the scope and ambit of the present invention.

[0032] In the foregoing specification, the invention has been described with reference to specific exemplary embodiments; however, it will be appreciated that various modifications and changes may be made without departing from the scope of the present invention as set forth in the claims below. The specification and figures are to be regarded in an illustrative manner, rather than a restrictive one and all such modifications are intended to be included within the scope of the present invention. Accordingly, the scope of the invention should be determined by the claims appended hereto and their legal equivalents rather than by merely the examples described above. For example, the steps recited in any method or process

claims may be executed in any order and are not limited to the specific order presented in the claims. Additionally, the components and/or elements recited in any apparatus claims may be assembled or otherwise operationally configured in a variety of permutations to produce substantially the same result as the present invention and are accordingly not limited to the specific configuration recited in the claims.

[0033] Benefits, other advantages and solutions to problems have been described above with regard to particular embodiments; however, any benefit, advantage, solution to problems or any element that may cause any particular benefit, advantage or solution to occur or to become more pronounced are not to be construed as critical, required or essential features or components of any or all the claims.

[0034] As used herein, the terms "comprises", "comprising", or any variation thereof, are intended to reference a non-exclusive inclusion, such that a process, method, article, composition or apparatus that comprises a list of elements does not include only those elements recited, but may also include other elements not expressly listed or inherent to such process, method, article, composition or apparatus. Other combinations and/or modifications of the above-described structures, arrangements, applications, proportions, elements, materials or components used in the practice of the present invention, in addition to those not specifically recited, may be varied or otherwise particularly adapted by those skilled in the art to specific environments, manufacturing specifications, design parameters or other operating requirements without departing from the general principles of the same.

16
CLAIMS

1. A method for making a micropump device, comprising:
 - providing a substrate, said substrate comprising a first surface and fluidic channels;
 - said fluidic channels comprising an inlet channel, an outlet channel and a pumping cavity;
 - said inlet channel suitably adapted to receive fluid for transport through said micropump device;
 - said outlet channel suitably adapted to purge fluid from said micropump device;
 - providing a first valve for effectively permitting flow of fluid from said inlet channel to said pumping cavity, said first valve effectively restricting backflow of purged fluid from said pumping cavity to said inlet, and said first valve deposited through a first opening on said first surface of said substrate;
 - providing a second valve for effectively permitting flow of fluid from said pumping cavity to said outlet channel, said second valve effectively restricting backflow of purged fluid from said outlet channel to said pumping cavity, and said second valve deposited through a second opening on said first surface of said substrate;
 - effectively disposing a pump actuator over said first opening;
 - and
 - providing a cover for substantially sealing said second opening.
2. The method of claim 1, wherein said first opening and said second opening comprise the same opening and said pump actuator comprises the cover.

3. The method of claim 1, wherein said first valve and said second valve comprise at least one of a check valve, a passive check valve and a flapper valve.
4. The method of claim 3, wherein said first valve and said second valve comprise at least one of silicone, silicone-based rubber, rubber, metal, metal alloy and polymer.
5. The method of claim 1, wherein said pump actuator comprises a piezoelectric element.
6. The method of claim 1, further comprising the step of providing means for retaining at least one of said first valve and said second valve within a microfluidic channel.
7. The method of claim 6, wherein said retaining means comprises at least one of a substantially annular retaining ring, a valve anchor and a seal.

- 8.** A microfluidic pumping device manufactured in accordance with the method of claim 1, wherein said pump actuator comprises a piezoelectric actuator.
- 9.** The microfluidic pumping device of claim 8, further comprising means for retaining at least one of said first valve and said second valve within a microfluidic channel.
- 10.** The microfluidic pumping device of claim 9, wherein said retaining means comprises at least one of a substantially annular retaining ring, a valve anchor and a seal.
- 11.** The microfluidic pumping device of claim 8, wherein said piezoelectric actuator comprises at least one of a unimorphic piezoelectric element and a bimorphic piezoelectric element.

12. A microfluidic pumping system comprising a plurality of micropump devices manufactured in accordance with the method of claim 1, wherein said plurality of micropumps are in common fluidic communication; and

said common fluidic communication of said micropumps comprises at least one of a series configuration and a parallel configuration.

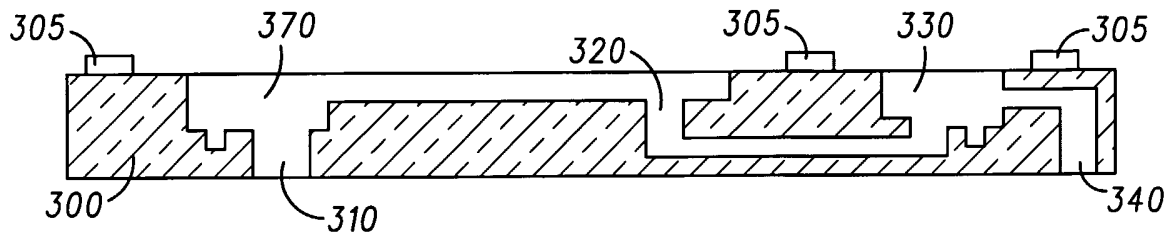


FIG. 1

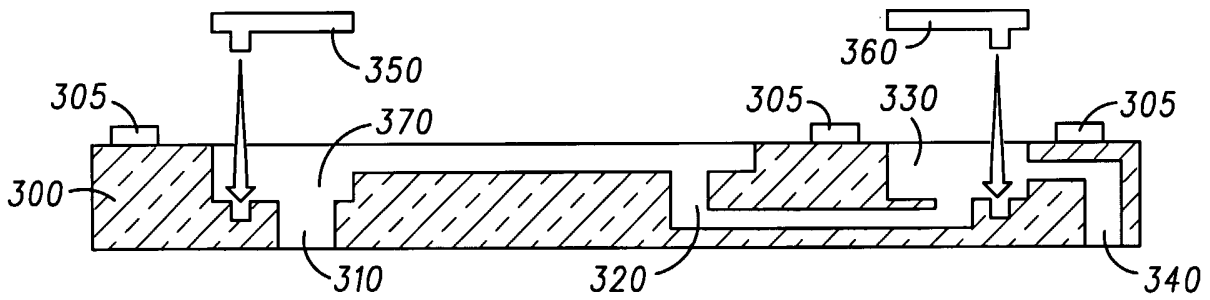


FIG. 2

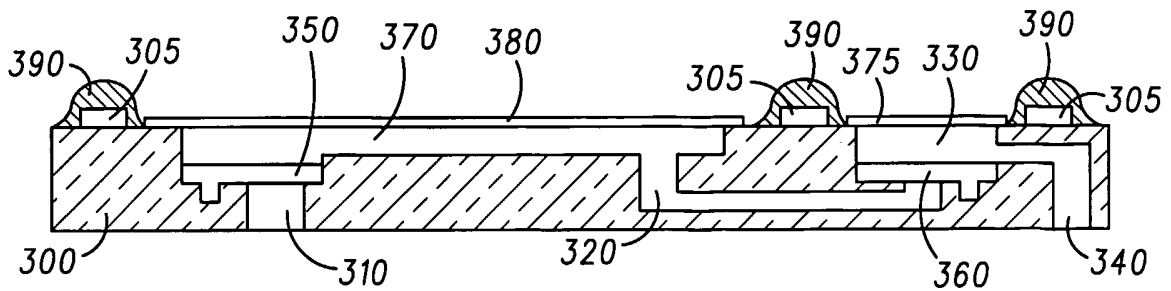


FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 03/22998

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F04B43/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 164 933 A (MASAKI YASUFUMI ET AL) 26 December 2000 (2000-12-26) abstract; figures 2,3,12-15,18-20	1-12
A	EP 0 435 653 A (SEIKO EPSON CORP) 3 July 1991 (1991-07-03) page 6, line 43 -page 8, line 49; figures	1-12
A	WO 01 21988 A (TAI YU CHONG ;WANG XUAN QI (US); CALIFORNIA INST OF TECHN (US)) 29 March 2001 (2001-03-29) abstract; claim 6; figure 1 page 10, line 11 -page 12, line 7	4-7
A	US 2002/098097 A1 (SINGH ANGAD) 25 July 2002 (2002-07-25) page 6, column 1, line 12 -page 7, column 2, line 46; figure 3	3-7

Further documents are listed in the continuation of box C.

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