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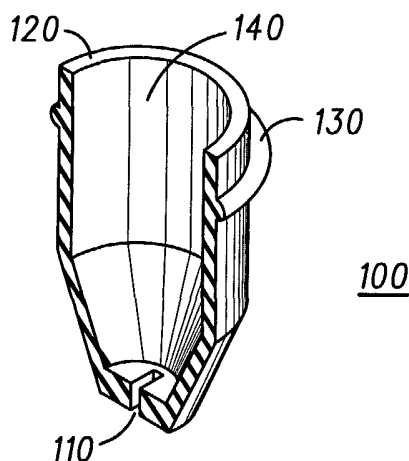
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(54) Title: CHECK VALVES FOR MICROPUMPS



(57) **Abstract:** An exemplary device and method for microfluidic transport is disclosed as providing inter alia a passive check valve (100), a fluid inlet channel (210), a fluid outlet channel (220) and a pumping cavity (240). The fluid inlet channel (210) is generally configured to flow a fluid through the check valve (100). The check valve (100) generally provides substantially passive means for preventing or otherwise decreasing the incidence of purged outlet fluid re-entering either the pumping cavity (240) or the fluid inlet channel (210). Accordingly, the reduction of backflow generally tends to enhance overall pumping performance and 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 micropumps that may be readily integrated with, for example, existing portable ceramic technologies for the improvement of device package form factors, weights and other manufacturing and/or device performance metrics.

CHECK VALVES FOR MICROPUMPS

FIELD OF INVENTION

- [0001]** The present invention relates to micropumps, and more particularly, in one representative and exemplary embodiment, to piezoelectrically actuated micropumps having passive check valves for improved performance and efficiency in microfluidic applications.

BACKGROUND

- [0002]** Development of microfluidic technology has generally been driven by parallel ontological advancements in the commercial electronics industry with an 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 ceramic structure to define, for example, a monolithic micropump device.

[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. Accordingly, conventional pump designs have generally not been regarded as suitable for integration with portable ceramic packages, microfluidic 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 monolithic 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 cost. 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 micropumps having integrated check valves suitably adapted for incorporation with, for example, a monolithic 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 cavity, a fluid outlet cavity, a passive check valve substantially enclosed within each of the cavities, and means for moving fluid through the device. An integrated micropump, in accordance with one embodiment of the present invention, may be formed utilizing multilayer ceramic technology in which passive check valves are integrated into a 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 depicts a cut-away section of a representative “duck-bill” passive check valve in accordance with an exemplary embodiment of the present invention;
- [0009] FIG. 2 representatively illustrates a piezoelectrically actuated micropump system utilizing the passive check valve of FIG. 1 in accordance with an exemplary embodiment of the present invention;
- [0010] FIG. 3 depicts a cut-away section of a representative passive check valve in accordance with another embodiment of the present invention; and
- [0011] FIG. 4 representatively illustrates a piezoelectrically actuated micropump system utilizing the passive check valve of FIG. 3 in accordance with yet another exemplary embodiment of the present invention.

- [0012] 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

- [0013] 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.
- [0014] 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.

[0015] A detailed description of an exemplary application, namely a system and method for pumping a fluid in an integrated microfluidic 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.

[0016] In one representative application, in accordance with an exemplary embodiment of the present invention, a passive check valve **100**, as generally depicted in FIG. **1**, is disclosed for application with a microfluidic pump. Check valve **100** generally comprises a valve housing **120** for providing a path for fluid transport from inlet opening **140** to outlet opening **110** where outlet fluid may subsequently be purged. Inlet opening **140**, 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 **140** and/or valve housing **120** and/or outlet opening **110**. For example, inlet opening **140** and/or valve housing **120** 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 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.

[0017] Outlet opening **110** generally comprises passive means for substantially preventing or otherwise controlling or restricting the backflow of purged outlet fluid into valve housing **120**. For example, outlet opening **110** may comprise features (*i.e.*, a "slit"; as representatively depicted in FIG. **1**) for effectively dilating outlet opening **110** 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 **140** through valve housing **120** toward outlet opening **110**. Additionally, outlet opening **110**, in accordance with representative

aspects of the present invention, conjunctively provides for effective constriction of outlet opening **110** when the fluid transport gradient corresponds to translation of fluid volume elements away from outlet opening **110** through valve housing **120** toward inlet opening **140** (e.g., “backflow”).

[0018] One such implementation of the present invention is depicted in the embodiment representatively illustrated in FIG. **1**, wherein outlet opening **110** comprises a slit. Skilled artisans will appreciate that the passive check valve **100** depicted in FIG. **1** may also be characterized as belonging to a general class of valves typically referred to as “duck-bill” type valves. Other means for providing substantially passive valving function, such as, for example: a plunger, a shuttle, a rotary stop-cock, a flap, 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 may be alternatively, conjunctively or sequentially used. 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 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).

[0019] In various exemplary embodiments, passive check valve **100** may be fabricated from silicone, silicone-based rubber, rubber, 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 valve **100** comprises a “duck-bill” type valve, as generally depicted, for example, in FIG. **1**, the passive check valve may comprise a silicone-based rubber material. Additionally, check valve housing **120** may optionally comprise a substantially annular retaining ring **130** for securing or otherwise at least partially immobilizing check valve **100a** within a device package substrate **200**. See, for example, FIG. **2**. Various other means for retaining, localizing or otherwise disposing check valves according to the present invention with respect to microfluidic channels may be used and/or other package features. For example, the following retaining means may be conjunctively, alternatively or sequentially employed: adhesives, organic epoxies, press-fit clips, solder, clamps, adaptors and/or such other retention, connection or attachment devices, means and/or methods, whether now known or otherwise hereafter described in the art.

[0020] FIG. **2** generally depicts two passive check valves **100a**, **100b** disposed within an exemplary monolithic package substrate **200**. The device package **200** generally comprises an input microfluidic channel **210**, an output microfluidic channel **220** and a piezoelectric micropump element **250**. In a representative and exemplary embodiment, piezoelectric element **250** may be secured to the package substrate **200** by, for example, epoxy **230**. Various other means for attaching piezoelectric element **250** to the package substrate **200** include, for example: solder, 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 micropump element **250** may alternatively be integrated within the package substrate; for example, between ceramic layers in a position substantially internal to the device package. In yet a further exemplary embodiment, the present invention may provide for integration external to the device package and/or surface mounted to the device package.

- [0021] As electric current is supplied to the piezoelectric element **250**, the piezoelectric element **250** operates as a deformable diaphragm membrane whose deformation (*e.g.*, “stroke volume”) causes oscillating over- and under-pressures in pump chamber **240**. Pump chamber **240**, in an exemplary embodiment, may be bounded by two passive check valves **100a**, **100b**. The pump actuation mechanism 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.
- [0022] During the movement of the diaphragm element (*i.e.*, piezoelectric element **250**) in a direction which tends to enlarge the pump chamber volume, an under-pressure is generated in pump chamber **240** causing fluid to flow through the inlet channel **210** into valve inlet **140a** of check valve **100a** in a flow direction which causes the valve’s outlet slit **110a** to dilate thereby permitting fluid to enter into pump chamber **240**. Since the fluid transport gradient during the under-pressure stroke is anti-parallel to the fluid flow acceptance conformation of check valve **100b**, the outlet slit **110b** of check valve **100b** constricts so as to at least partial reduce the occurrence of fluid disposed in outlet channel **220** re-entering pump chamber **240** (*e.g.*, backflow). Accordingly, this component of the pump cycle is termed the “supply mode” or the “supply stroke”.
- [0023] In the alternate and next phase of the stroke cycle, the movement of the diaphragm element in a direction which tends to reduce the pump chamber volume causes an over-pressure to be generated in pump chamber **240**, thereby flowing fluid through the outlet **110b** of check valve **100b** as a result of fluid flowing out of pump chamber **240** into valve inlet **140b** in a flow direction which causes the valve’s outlet slit **110b** to dilate thereby permitting fluid to enter into outlet channel **220**. Since the fluid transport gradient during the over-pressure stroke is anti-parallel to the fluid flow acceptance conformation of check valve **100a**, the outlet slit

110a of check valve **100a** constricts so as to at least partial reduce the occurrence of fluid disposed in outlet channel **220** from back-flowing into the inlet channel **210**. Accordingly, this component of the pump cycle is termed the “pumping mode” or the “delivery stroke”.

[0024] 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.

[0025] 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 **240** 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 $|\Delta p| \geq |p'|$.

[0026] 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 **240** 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.

[0027] 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:

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

[0028] Accordingly, it may be shown that the criterion for the compression ratio

of a gas micropump may be similarly derived as $\varepsilon_{gas} \geq \left(\frac{p_0}{p_0 - |p'|} \right)^{\frac{1}{\gamma}} - 1$ 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 μl .

[0029] In conventional micropump operation, gas bubbles may often remain in the pump chamber during the priming procedure 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.

[0030] 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 **210** into the pump chamber **240**, 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.

[0031] In an alternative embodiment, in accordance with another exemplary aspect of the present invention as representatively depicted, for example, in FIG. 3, a passive check valve **300** may be provided with a substantially flexible flap **320** distally located from valve outlet **310** and annularly peripheral or otherwise concentric to valve inlet **340**. This combination "umbrella" / "duck-bill" valve design has the benefit of *inter alia* generally requiring only one substantially unitary valving element for effective valve

actuation and device operation as representatively illustrated, for example, in FIG. 4. During the movement of the diaphragm element (*i.e.*, piezoelectric element **250**) in a direction which tends to enlarge the pump chamber **240** volume, an under-pressure is generated in pump chamber **240** causing peripheral flap **320** to distend in a direction toward diaphragm element **250** thereby opening inlet channel **410** to permit fluid to enter into pump chamber **240**. Since the fluid transport gradient during the under-pressure stroke is anti-parallel to the fluid flow acceptance conformation of check valve **300**, the outlet slit **310** of check valve **300** constricts so as to at least partially reduce the occurrence of fluid disposed in outlet channel **420** re-entering via backflow into pump chamber **240**.

[0032] In the alternate next phase of the stroke cycle, the movement of the diaphragm element **250** in a direction which tends to reduce the pump chamber volume causes an over-pressure to be generated in pump chamber **240** thereby causing fluid to flow through the outlet **310** of check valve **300** as a result of fluid flowing out of pump chamber **240** into valve inlet **340** of check valve **300** in a flow direction which causes the valve's outlet slit **310** to dilate thereby permitting fluid to enter into outlet channel **420**. Since the fluid transport gradient during the over-pressure stroke tends to press the peripheral "umbrella" flap **320** down against the pump chamber wall in the vicinity of inlet channel **410**, the effect is to at least partially reduce the occurrence of fluid disposed in the pump chamber **240** from back-flowing into the inlet channel **410**. Those skilled in the art will appreciate various other geometries and/or arrangements of multiple valve components may be otherwise employed to achieve substantially the same result as the exemplary embodiments disclosed herein. The same shall be regarded as within the scope and ambit of the present invention.

[0033] 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.

[0034] 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.

[0035] 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

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in the art to specific environments, manufacturing specifications, design parameters or other operating requirements without departing from the general principles of the same.

CLAIMS

1. A passive check valve for use with a microfluidic pump, comprising:
 - a valve housing, a inlet opening and a outlet opening;
 - said inlet opening suitably adapted to receive inlet fluid for transport through said valve housing;
 - said valve housing effectively confining transport of inlet fluid from said inlet opening to said outlet opening where outlet fluid is purged;
 - said outlet opening comprising passive means for substantially restricting backflow of purged outlet fluid back into the valve housing.
2. The passive check valve of claim 1, wherein said means for restricting the backflow of purged outlet fluid comprises:
 - means for effectively dilating said outlet opening when the direction of fluid pressure tends to flow fluid in a direction away from said inlet opening through said valve housing toward said outlet opening; and
 - means for effectively constricting said outlet opening when the direction of fluid pressure tends to flow fluid in a direction away from said outlet opening through said valve housing toward said inlet opening.
3. The passive check valve of claim 2, wherein said passive check valve comprises at least one of silicone, silicone-based rubber, rubber and polymer.
4. The passive check valve of claim 2, further comprising means for retaining said check valve within a microfluidic channel.
5. The passive check valve of claim 4, wherein said retaining means comprises a substantially annular retaining ring.

6. The passive check valve of claim 2, further comprising an substantially flexible umbrella flap distally located from said outlet opening and annularly peripheral to said inlet opening.
7. The passive check valve of claim 1, wherein said means for restricting the backflow of purged outlet fluid comprises a duck-bill valve.
8. The passive check valve of claim 7, further comprising an substantially flexible umbrella flap distally located from said outlet opening and annularly peripheral to said inlet opening.
9. A method of fabricating a multilayer micropump device comprising:
- providing a plurality of substrate layers;
 - forming into said plurality of substrate layers a channel and a cavity, said channel and said cavity in microfluidic communication to define a fluid channel and a pumping cavity;
 - placing within said fluid channel a passive check valve according to claim 1; and
 - laminating each of the plurality of substrate layers to form a substantially monolithic micropump device.
10. The method of claim 9, further comprising the step of providing a pumping actuator element on a surface of said monolithic package, said pumping actuator suitably adapted to exert a pumping force as a result of application of a voltage to the monolithic micropump package.
11. A duck-bill passive check valve for use with a microfluidic pump, comprising:
- a valve housing, an inlet opening and an outlet opening;

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said inlet opening suitably adapted to receive inlet fluid for transport through said valve housing;

said valve housing effectively confining transport of fluid from said inlet opening to said outlet opening;

said outlet opening comprising a slit; and

said outlet opening slit effectively permitting the purging of outlet fluid from said valve while substantially restricting backflow of purged outlet fluid from re-entering said valve.

12. The passive check valve of claim **11**, further comprising a substantially flexible umbrella flap distally located from said outlet opening and annularly peripheral to said inlet opening.

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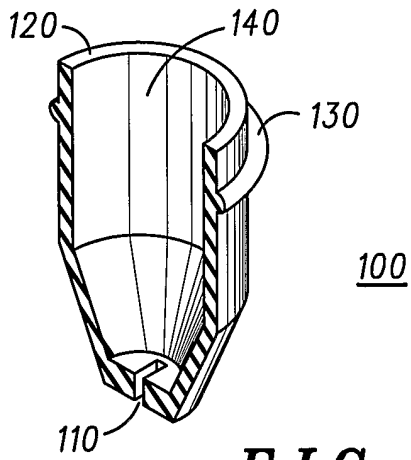


FIG. 1

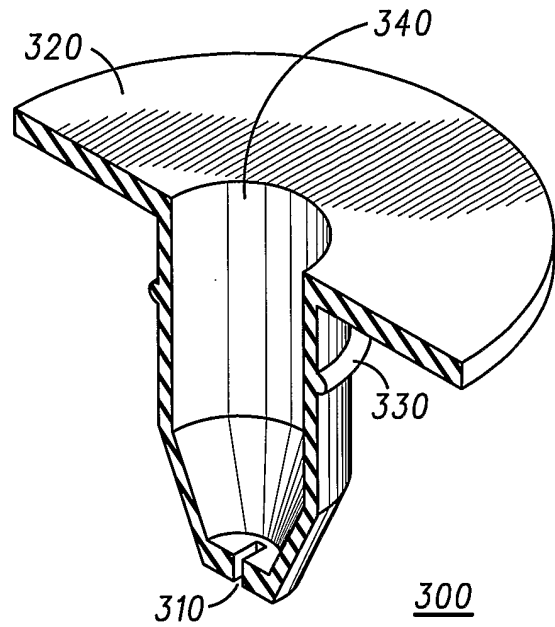


FIG. 3

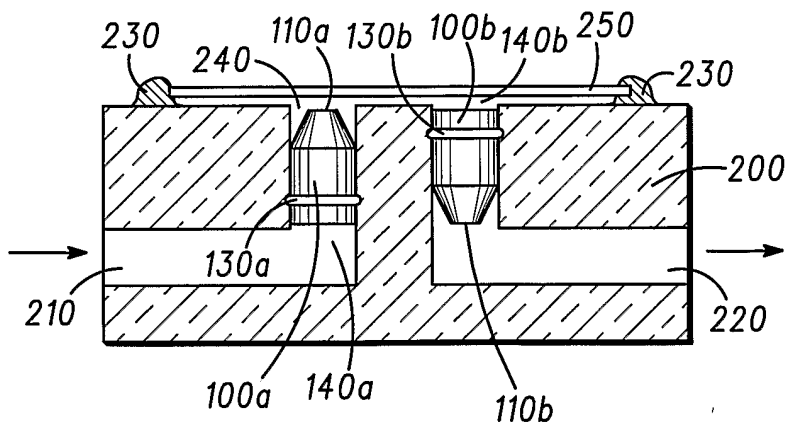


FIG. 2

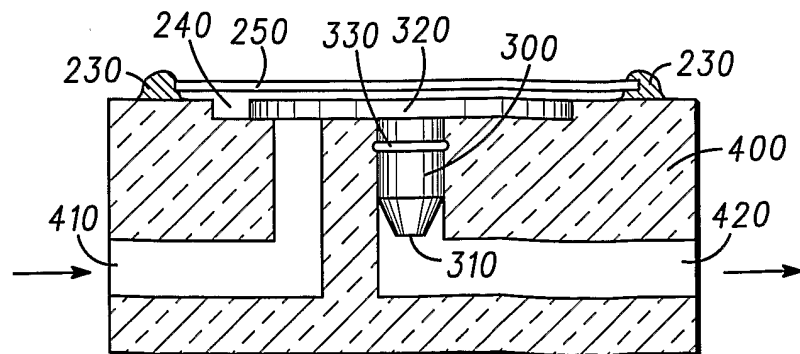


FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 03/22405

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 F04B53/10 F04B43/04 F16K15/14

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 F16K

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, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 669 764 A (BEHRINGER BRUCE E ET AL) 23 September 1997 (1997-09-23) abstract column 2, line 51 - column 3, line 26 column 4, line 3 - line 45 figures 1,3 ---	1-5,7,11 9
X A	US 4 030 495 A (VIRAG ROBERT ANTHONY) 21 June 1977 (1977-06-21) abstract column 3, line 21 - line 50 figures 1,2 --- -/--	1,2,4, 6-8,11, 12 3

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

6 November 2003

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Internati Application No
PCT/US 03/22405

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	DE 42 39 464 A (HEINZL JOACHIM) 26 May 1994 (1994-05-26) abstract column 2, line 40 - line 61 column 3, line 51 - column 4, line 1 figures 1,6 ---	1,2,4,7, 11 3,9
X A	US 6 425 740 B1 (DAVIS CLARK C ET AL) 30 July 2002 (2002-07-30) abstract column 1, line 11 - line 23 column 2, line 12 - line 16 column 3, line 56 - line 67 column 8, line 4 - line 34 figures 3,7,8 ---	1,2,4,7, 9,11 3
X A	US 5 759 014 A (VAN LINTEL HARALD) 2 June 1998 (1998-06-02) abstract column 4, line 54 - column 5, line 48 figures 4,5 -----	1-4,7,11 9

INTERNATIONAL SEARCH REPORT

Information on patent family members

Internati

pplication No

PCT/US 03/22405

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5669764	A	23-09-1997	US 5934885 A	10-08-1999
			US 5902096 A	11-05-1999
			AU 697402 B2	08-10-1998
			AU 3292495 A	18-04-1996
			CA 2159434 A1	08-04-1996
			EP 0705978 A2	10-04-1996
			IL 115327 A	13-08-2000
			JP 8210256 A	20-08-1996
			NO 953980 A	09-04-1996
US 4030495	A	21-06-1977	AU 1924976 A	11-05-1978
			BE 848024 A1	01-03-1977
			BR 7607419 A	20-09-1977
			CA 1070585 A1	29-01-1980
			DE 2649813 A1	18-05-1977
			DK 491276 A	08-05-1977
			ES 453082 A1	01-11-1977
			FR 2330883 A1	03-06-1977
			GB 1522727 A	31-08-1978
			IL 50733 A	12-03-1979
			IT 1063549 B	11-02-1985
			JP 52059986 A	17-05-1977
			NO 763764 A ,B,	10-05-1977
			ZA 7606600 A	26-10-1977
DE 4239464	A	26-05-1994	DE 4239464 A1	26-05-1994
US 6425740	B1	30-07-2002	AU 7701201 A	13-02-2002
			CN 1444699 T	24-09-2003
			EP 1305522 A1	02-05-2003
			WO 0210590 A1	07-02-2002
			US 2002175520 A1	28-11-2002
US 5759014	A	02-06-1998	CH 689836 A5	15-12-1999
			AU 679311 B2	26-06-1997
			AU 1326395 A	01-08-1995
			CA 2181084 A1	20-07-1995
			DE 69500529 D1	11-09-1997
			DE 69500529 T2	12-03-1998
			EP 0739451 A1	30-10-1996
			ES 2107908 T3	01-12-1997
			WO 9519502 A1	20-07-1995
			JP 9512075 T	02-12-1997