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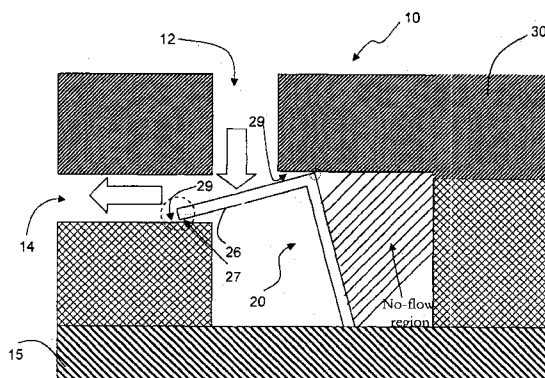


FIGURE 8

(57) Abstract: A passive microvalve actuated by the deformation of the microvalve structure (20) (such as bending and rotation) due to fluid pressure exerted is disclosed. The deformation of the valve structure (20) directs fluid flow to a desired pathway and reduce occurrence of dead volume. A basic embodiment of our microvalve is comprised in a semiconductor-fabricated body (10) regulating fluid flow between at least a first channel (12) and a second channel (14) in a passive manner, with the microvalve fabricated as an integral cantilever structure (20) comprising a stem (22) with base (24) rigidly affixed to a substrate (15); and at least a lever arm (26) extending at about tangentially from distal end of the stem (22), forming an elbow (28) thereat. The cantilever structure (20) may comprise of any one of L-shape or T-shape structure formed via MEMS processes, particularly surface micro-machining (SMM) processes so that our proposed valve may be fabricated cost-effectively, robust and easily integrated into semiconductor devices.

## Cantilever microvalve structure and method of fabricating same

### 5 TECHNICAL FIELD

[001] This invention relates to micro-electromechanical systems (MEMS) for microfluidic control systems. In particular, it relates to a microvalve structure that may be fabricated with surface micromachining (SMM) technology in  
10 which the microvalve may be useful as passive micro-check valve in semiconductor devices for precise and/or automatic dosing in drug delivery and sensing systems.

### 15 BACKGROUND ART

[002] Micro-check valve is one of the most critical components of a microfluidic system wherein it acts as the controlling element over fluid flow actuation. Most of the micro-check valves today are active devices wherein  
20 power input is required for the actuation of the valve structure. Such active micro-valve structure may be complex and difficult to fabricate and suffers from difficulties in integration into microfluidic systems. This is because the valve structure of these active devices must be fabricated with functionalised parts or surfaces such as providing for a mono- or bi-layer of electro-statically  
25 functional or metallic surface of an actuating structure. Bi-layering with 2 layers of materials having different thermal expansion coefficients have also been used in bi-morph and poppet (boss) valves.

[003] A common valve actuating structure employed in microvalves is the  
30 cantilever beam structure which may be fabricated with conventional bulk-micromachining. An example of an electrostatic-actuated cantilever beam

valve is described in Mueller (1997)<sup>1</sup>. Such cantilever beams in which the base or anchor to the substrate is provided in form of a step have also been disclosed in U.S. Patent No. 5,819,749 (Lee) wherein an array of such valves is disclosed, and U.S. Patent No. 6,236,491 (Goodwin-Johansson) wherein an air gap  
5 between the cantilever and substrate is disclosed to be an important factor in achieving the desired inflection of the cantilever beam.

[004] Large deflection due to heat deformation of cantilever structures in combination with shape memory alloy parallel beam has also been disclosed in  
10 U.S. Publication No. 2006/38643 (Xu). For passive microvalves wherein actuation is achieved by mechanical means, a cantilever-type flap made from thin layers of silicon, metal or polymers is described in Kwang W. Oh (2006)<sup>2</sup> which is evidently different from beam-type cantilever structures. The non-rigidity and bending characteristics of such prior art cantilever structures  
15 made by surface micromachining have been studied and presented as an analytical modelling by the first two of the present co-inventors, Hing Wah Lee (2006)<sup>3</sup>. It is shown in this study that the presence of finite anchor stiffness due to the non-rigid effect yields significant difference on the deflections of the cantilever structure and that the anchor's flexibility should be considered to  
20 achieve accuracy.

[005] Apart from the disadvantage that such active microvalve structures consume power and are costly to fabricate due to its complexity, these prior art structures only provide a single direction of fluid flow control, i.e. fluid flow  
25 cannot be directed to a specific required path. This in turn creates fluid dead volume in the valve device, making precise fluid dispensing difficult to achieve. Another problem with active valve structures is the need to provide functionalized surfaces or parts on the structure, for example, in order to enable electrostatic actuation. Such functionalized parts or layers are  
30 susceptible to undesirable variations in performance due to effects arising from the conducted fluid's pH or ionic properties.

[006] It is thus desirable to have a microvalve that could actuate passively, i.e. without the need for power input, e.g. actuated by fluid pressure, so that the design for such microvalve structure and semiconductor body may be simplified and cost-effective, in addition to capability of directing fluid flow in a manner that would avoid dead volume and its performance not affected by the ionic properties of the fluid to be delivered or conducted.

## 10 SUMMARY OF DISCLOSURE

[007] Our proposed invention is a passive microvalve which will be actuated by the deformation of the valve structure (such as bending and rotation) due to fluid pressure exerted and does not require any power input for the actuation. The deformation of the valve structure endeavours to direct fluid flow to a desired pathway and reduce occurrence of dead volume. It is also desirable that our proposed microvalve may be fabricated with MEMS processes including surface micromachining (SMM) so that our proposed valve may be fabricated cost-effectively, robust and may be easily integrated into other devices using standard MEMS processes.

[008] A basic embodiment of our microvalve is comprised in a semiconductor-fabricated body regulating fluid flow between at least a first channel and a second channel in a passive manner, said microvalve fabricated as an integral cantilever structure comprising a stem with base rigidly affixed to a substrate; and at least a lever arm extending at about tangentially from distal end of said stem, forming an elbow thereat.

[009] In one aspect of our microvalve structure, the cantilever structure is fabricated to predetermined bending stiffness, anchor stiffness or rotational moment at at least one of said stem base and elbow. Preferably, the cantilever

structure is normally in close position against one of said channels and opens by fluid pressure exerting on at least one surface of the stem or lever arm.

[010] In a second aspect, the cantilever structure regulates fluid flow by deformation of at least one of its stem, elbow and/or lever arm. The deformation preferably includes any one or combination of bending and/or rotation of the stem, elbow and/or lever arm. More preferably, the deformation of at least part of the cantilever structure includes deflection to an extent in which the tip of at least one of the lever arm or elbow touches an opposing surface of a channel thereby directing fluid flow in a predetermined direction and avoiding dead volume.

[011] In a third aspect, the cantilever structure may comprise of any one of L-shape or T-shape structure formed via surface micromachining processes. Preferably, the lever arm of the L-shape structure or lever arms of T-shape structure extends to at least 40% of the length of the stem. Preferably still, the base of the cantilever structure's stem is constrained rigidly on a silicon substrate comprising a silicon nitride ( $\text{Si}_3\text{N}_4$ ) layer on silicon wafer.

[012] In a fourth aspect, the cantilever structure is disposed in the semiconductor-fabricated body as valve control over 2 fluid flow channels, including a first inlet channel to a first outlet channel and a second inlet channel to a second outlet channel. Preferably, the cantilever structure is deformable to simultaneously actuate valve control over both fluid flow channels. Alternatively, the cantilever structure is deformable such that a tip of an extended lever arm is used to crimp or bend a flexible nanotube forming said fluid flow channel.

[013] Our proposed microvalve cantilever structure may be fabricated with surface micromachining techniques, including the steps of (a) depositing a layer of silicon nitride ( $\text{Si}_3\text{N}_4$ ) (13) on a silicon wafer (11); (b) depositing or

growing and forming a pattern of sacrificial oxide layer; (c) depositing a polysilicon layer over the patterned sacrificial formed in step (b) above; (d) patterning said polysilicon layer to form a cantilever valve structure; and (e) removing said sacrificial oxide layer. The sacrificial oxide layer is preferably phosphosilicate glass (PSG) and the removal of the sacrificial oxide layer in step (e) involves buffer oxide etching (BOE).

#### LIST OF ACCOMPANYING DRAWINGS

[014] The drawings accompanying this disclosure serve to illustrate specific and exemplary embodiments of our microvalve structure and process of fabricating it without limiting or constraining the working principles of our invention.

[015] FIGURE 1 is a schematic drawing of the relative placement of a microvalve in a microfluidic system.

[016] FIGURE 2 schematically illustrates an L-shaped cantilever microvalve structure according to our invention in which the stiffness points are indicated.

[017] FIGURE 3 schematically shows a free body diagram of a hypothetical L-shape microvalve proposed upon application of fluid pressure.

[018] FIGURE 4 represents a summary of the displacement for different ratio of beam length (vertical/horizontal) at different applied fluid pressure.

[019] FIGURE 5 displays a numerical simulation showing deformation of an L-microvalve in Z-displacement.

[020] FIGURE 6 shows a numerical simulation showing deformation of an L-microvalve in Y-displacement.

[021] FIGURE 7 and FIGURE 8 show an embodiment of an L-microvalve according to our invention for controlling a single flow path in its normally closed and opened under fluid pressure, respectively.

[022] FIGURE 9 and FIGURE 10 illustrate another embodiment of an L-microvalve of our invention for controlling two flow paths in its normally closed and opened under fluid pressure, respectively.

[023] FIGURE 11 schematically represents a series of steps in the fabrication of an L-shape microvalve structure on a semiconductor device.

[024] FIGURE 12 schematically illustrates a T-shaped cantilever microvalve structure according to our invention in which the stiffness points are indicated.

[025] FIGURE 13 schematically shows a free body diagram of a hypothetical T-shape microvalve proposed upon application of fluid pressure.

[026] FIGURE 14 and FIGURE 15 illustrate an embodiment of a T-microvalve of our invention for controlling a single flow path in its normally closed and opened under fluid pressure, respectively.

[027] FIGURE 16 schematically represents a series of steps in the fabrication of a T-shape microvalve structure on a semiconductor device.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[028] In a microfluidic system fabricated within a semiconductor device, such as the one shown schematically in FIGURE 1, fluid flow pathway is typically provided for a fluid to enter the device from an inlet (62) through an incoming microchannel (64). A micropump (66) may be optionally provided to drive the fluid through, or provide the necessary pressure to actuate, the microvalve body (10) which contains a passive actuating element (20) such as a cantilever structure. Upon actuation, the fluid will flow via an outgoing microchannel (74) through an outlet (72).

[029] Such passive actuation of micro check valve may find uses in microfluidic systems for many applications including biochemical analysis, drug delivery, agriculture, environmental monitoring and in microanalyser systems. Our proposed microvalve structure and device incorporating it may be fabricated using semiconductor fabrication processes, particularly those for MEMS such as surface micromachining (SMM).

[030] In the basic configuration, with reference to FIGURE 7, our proposed microvalve is comprised in a semiconductor-fabricated body (10) regulating fluid flow between at least a first channel (12) and a second channel (14) in a passive manner. The proposed microvalve is fabricated as an integral cantilever structure (20) comprising a stem (22) with base (64) rigidly affixed to a substrate (15) and at least a lever arm (26) extending at about tangentially from distal end of said stem (22), forming an elbow (28) thereat.

[031] The cantilever structure (60) may take the shape of of an L-shape (20) or T-shape (30) (shown in FIGURES 12 – 16 and further described later) which may be formed via SMM processes. We shall describe the L-shape embodiment first in the following bearing in mind that many of the features described may be common to both L- and T-shape cantilever structures.

[032] Our proposed passive cantilever structure (20) may be configured to be in a normally close position against one of the fluid flow channels such that it is only opened by fluid pressure exerting on the cantilever structure (20), e.g. by pressure exerted on a surface of the stem (22), as shown in FIGURE 8 for single valve checking. Fluid pressure may also be arranged to be exerted on a lever arm (26) as shown in FIGURE 10 for bi-directional valving. The actuation of the cantilever structure (20) involves combined deformation of its stem (22), elbow (28) and/or lever arm (26), i.e. may involve bi-directional movement of the microvalve structure (20) in both horizontal and vertical displacement. This can be further achieved with the compounding effect of the rotational stiffness at the anchor (28) of the structure.

[033] Although this embodiment is configured to actuate as a normally closed check valve, it is possible to fabricate one as a normally open valve for a first fluid flow pathway whereby pressure from a second fluid flow pathway may be employed to deform the aforesaid parts of the microvalve structure to close the valve opening of the first fluid flow pathway. In either configuration, no power input is required to actuate our proposed microvalve structure. As the degree of deformation of the microvalve structure is dependent on the fluid pressure exerted, its actuation is more consistent with most types of fluids to be conducted therethrough, regardless of conductive or non-conductive types or regardless of the ionic properties or pH of the fluid.

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[034] To achieve the desired amount and direction of deformation of the microvalve structure, it is important that our proposed cantilever structure (20) be fabricated to predetermined bending stiffness, anchor stiffness or rotational moment at the stem base (24) and elbow (28) based on the materials used to form the cantilever structure as well as the relative lengths of the arm (26) and stem (22). Preferably, the cantilever structure is fabricated from polysilicon materials with its stem base (24) planted or constrained rigidly on a silicon substrate (15) as illustrated in FIGURE 2 wherein the bending stiffness

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of the ends of the structure, i.e. base of the stem (24) and end of the lever arm (26) are represented by the constant,  $K$ , while the anchor stiffness of the elbow (28) is represented by the constant,  $K_\theta$ . Preferably, the silicon substrate (15) comprises silicon nitride ( $\text{Si}_3\text{N}_4$ ) (13) layer on a silicon wafer (11) as shown in FIGURES 9 – 10.

[035] The L-shape embodiment of the microvalve structure may have its actuation calculated based on the principle of conventional beam bending theory with the addition of a rotational moment ( $M_\theta$ ) at the anchor. The free body diagram is shown in FIGURE 3 wherein is shown all the resultant forces and moment upon application of external fluid pressure.

[036] Through analytical beam bending analysis, the deflection of the L-microvalve at the vertical direction (y-direction),  $w$  can be given as Equation 1 [1] below:

$$\frac{w}{P} = \frac{l^4}{8EI} + \frac{l^3}{2K_\theta} \quad [1]$$

and the anchor stiffness due to the rotation can be evaluated in Equation 2 as:

$$K_\theta = \frac{l^3}{2} \left( \frac{1}{K} + \frac{l^4}{8EI} \right)^{-1} \quad [2]$$

where

|     |   |                                              |
|-----|---|----------------------------------------------|
| $l$ | = | horizontal beam length ( $\mu\text{m}$ )     |
| $K$ | = | horizontal beam stiffness ( $\mu\text{m}$ )  |
| $E$ | = | modulus of elasticity (MPa)                  |
| $I$ | = | second moment of inertia ( $\mu\text{m}^4$ ) |

[037] The value of the anchor stiffness will be specific for a given beam length, width and thickness. A comparison of the displacement obtained for conventional cantilever beam with the present invention is shown in Table 1.

TABLE 1: Comparison in the analytical model for deflections of conventional cantilever and L-microvalve

| Scheme       | Vertical displacement                                   |
|--------------|---------------------------------------------------------|
| L-microvalve | $\frac{w}{P} = \frac{l^4}{8EI} + \frac{l^3}{2K_\theta}$ |
| Cantilever   | $\frac{w}{P} = \frac{l^4}{8EI}$                         |

5

[038] Note that the horizontal displacement of the L-microvalve is similar to the vertical displacement as given by conventional cantilever scheme. A summary of the results obtained from numerical analysis on the displacement of the horizontal beam upon application of fluid pressure is displayed in Table

10 2 below.

TABLE 2: Results for displacement of L-cantilever subjected to different fluid pressure

| Pressure (MPa) | Vertical beam length (μm) | Horizontal beam length (μm) | Y-displacement (μm) | Z-displacement (μm) | Ratio % (Y/Z) |
|----------------|---------------------------|-----------------------------|---------------------|---------------------|---------------|
| 1              | 2                         | 5                           | 2.60E-02            | 1.37E-01            | 18.92         |
|                | 2.5                       | 5                           | 3.63E-02            | 1.58E-01            | 23.03         |
|                | 3                         | 5                           | 4.85E-02            | 1.78E-01            | 27.27         |
|                | 3.5                       | 5                           | 6.25E-02            | 1.98E-01            | 31.57         |
|                | 4                         | 5                           | 7.84E-02            | 2.18E-01            | 35.91         |
|                | 4.5                       | 5                           | 9.60E-02            | 2.38E-01            | 40.29         |
|                | 5                         | 5                           | 1.15E-01            | 2.58E-01            | 44.69         |
| 5              | 2                         | 5                           | 1.18E-01            | 6.77E-01            | 17.41         |
|                | 2.5                       | 5                           | 1.65E-01            | 7.71E-01            | 21.44         |
|                | 3                         | 5                           | 2.22E-01            | 8.63E-01            | 25.72         |
|                | 3.5                       | 5                           | 2.85E-01            | 9.53E-01            | 29.93         |
|                | 4                         | 5                           | 3.54E-01            | 1.04E+00            | 34.06         |
|                | 4.5                       | 5                           | 4.27E-01            | 1.12E+00            | 38.10         |
|                | 5                         | 5                           | 5.04E-01            | 1.20E+00            | 42.00         |

|    |     |   |          |          |       |
|----|-----|---|----------|----------|-------|
| 10 | 2   | 5 | 2.22E-01 | 1.31E+00 | 16.93 |
|    | 2.5 | 5 | 3.12E-01 | 1.48E+00 | 21.08 |
|    | 3   | 5 | 4.11E-01 | 1.64E+00 | 25.12 |
|    | 3.5 | 5 | 5.17E-01 | 1.80E+00 | 28.67 |
|    | 4   | 5 | 6.26E-01 | 1.95E+00 | 32.18 |
|    | 4.5 | 5 | 7.59E-01 | 2.08E+00 | 36.50 |
|    | 5   | 5 | 8.80E-01 | 2.20E+00 | 40.00 |

[039] The displacement for different ratio of beam length (vertical/horizontal) at different applied fluid pressure is shown as a graph in FIGURE 4. Using *CoventorWare*<sup>™</sup> software for numerical MEMS simulation, the deformation of the L-shape microvalve with results simulated for Z-displacement is obtained and shown in FIGURE 5 while that for Y-displacement is shown in FIGURE 6.

[040] Following the normally closed position of the microvalve structure (20) in FIGURE 7, upon application of the fluid pressure at the top surface of the lever arm (26), the L-shape cantilever microvalve (20) will be displaced both vertically downwards due to the horizontal beam-bending of the lever arm (26) and horizontally forward (shown leftwards in FIGURE 8) due to the vertical beam-bending of the stem (22) by the anchor rotational effect. In contrast to conventional cantilever-type microvalves, the present invention will have a fluid directing effect due to the horizontal forward movement of the stem (22). This deformation will reduce the occurrence of dead volume due to the fluid-flow directing-effect.

[041] Since the anchor (28) will also move vertically upwards during actuation, the L-shape microvalve will also be able to be stopped from further displacing when the anchor (28) connects with top substrate of the package (30). In effect, this self-limiting deflection to the extent whereby the tip (27) of the lever arm (26) or elbow (28) touches an opposing surface (29) of a channel, thereby directing fluid flow in a predetermined direction and avoiding dead volume.

[042] In a preferred embodiment, the cantilever structure (20) may be constructed within a semiconductor-fabricated body or package (10) in which the valve structure may be used for bi-directional valve-checking, i.e. valve control of 2 separate fluid flows with a single valve structure. This is shown in FIGURES 9 – 10 wherein the L-shape microvalve structure is used for injection of a first fluid flowing through a first pathway comprising a first inlet channel (12) to a first outlet channel (14) upon actuation of the valve by a second fluid flowing through the stem (22) being bent horizontally forward (shown leftward diagrammatically) due to the second fluid pressure.

[043] Therefore, one (i.e. the second) fluid flowing from a second inlet channel (16) to a second outlet channel (18) may be used to control the release of another (first) fluid from a reservoir due to the bending and rotational effect of the horizontal lever arm (26). In a different aspect, it may also be said that the cantilever structure (20) is deformable to simultaneously actuate valve control over said both fluid flow channels. It should be noted that the first or second inlet channels may be designed to be connected to a reservoir containing fluids to be delivered and controlled by the microvalve. Similarly, the outlet channels may also be provided to be connected to a reservoir for storing fluids to be collected.

[044] This feature is expected to be useful for applications such as pressure monitoring, bio-sensing, flood monitoring etc. For example, in a monolithically-integrated semiconductor sensor for fluorescence detection on a microfluidic platform, the fluid in the reservoir injected could act as the fluorescent dye (e.g. IR-800 dye in methanol) for optical detection. The bending of the stem (22) also acts as a microchannel directing excess fluid for removal through a fluid passage which opens above the horizontal lever arm (26).

[045] A general fabrication process for forming an L-shape cantilever microvalve structure is shown in FIGURE 11 which illustrates schematically the process steps (a) to (f). Typically, the fabrication process will involve surface micromachining technology for MEMS, including steps of:

- 5 (a) depositing a layer of silicon nitride ( $\text{Si}_3\text{N}_4$ ) (13) on a silicon wafer (11);
- (b) depositing or growing and forming a pattern of sacrificial oxide layer;
- (c) depositing a polysilicon layer over the patterned sacrificial formed in step (b) above;
- (d) patterning said polysilicon layer to form a cantilever valve structure;
- 10 and
- (e) removing said sacrificial oxide layer

which is readily understood by a person skilled in the art without further elaboration of any special considerations for our present invention.

15 [046] The sacrificial oxide layer is preferably phosphosilicate glass (PSG) while the removal of the sacrificial oxide layer in step (e) ideally involves buffer oxide etching (BOE). A more preferably structure would be a micro-machined cantilever structure (20) with the stem (22) comprising at least 40% of the horizontal lever arm (26) with the stem base (24) rigidly constrained at  
20 the silicon substrate (15). Depending on the relative lengths of the stem (22) and lever arm (26), high aspect ratio (HAR) etching techniques may also be useful in our fabrication process.

[047] As explained earlier, apart from the L-shape cantilever (20), it is also  
25 possible to fabricate a T-shape cantilever structure (30) that works in about the same manner as the afore-described L-shape structure (20). The corresponding schematic illustration of the stiffness points and free body diagram of the T-shape cantilever (30) are represented in FIGURES 12 – 13 while FIGURES 14 – 15 illustrate its actuation whereby it may be seen that  
30 its other arm (32) extending in the opposing direction of lever arm (26) may serve as a feature limiting the horizontal forward bending of the stem (22) or

the downward bending of the lever arm (26) upon the tip of the other arm (32) contacting the upper substrate. A series of process steps for fabricating a T-shape microvalve structure is suggested in FIGURE 16.

5 [048] It will be obvious to a person skilled in the art that many of the above microvalve configuration, actuation and fabrication process may be adapted or modified in a number of ways which would employ the teachings and working principles disclosed herein. For instance, the bi-directional actuation may be adapted or modified such that one of the 2 fluid flow pathways may be  
10 modified to be provided as a flexible nanotube which may be crimped by an adapted tip of the lever arm (26) to stop fluid flow in the nanotube as a second fluid exerts pressure against the cantilever valve to actuate the crimping action.

15 [049] Such configuration may be adapted from Solares (2002)<sup>4</sup> which is cited here as an enabling art adaptable from the original electrostatic actuation. Therefore, apart from fabricating our cantilever structure for valve actuation of fluid channel which is integral with a semiconductor package, it is also possible to fabricate it for valve checking purposes of a tubular element  
20 forming the fluid channel which is not integral with or within the semiconductor package. These modifications and adaptations are to be considered as falling within the letter and scope of our invention as defined in the following claims.

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## CLAIMS

- 5 1. A microvalve comprised in a semiconductor-fabricated body (10) regulating fluid flow between at least a first channel (12) and a second channel (14) in a passive manner, said microvalve fabricated as an integral cantilever structure (20) comprising:
- a stem (22) with base (24) rigidly affixed to a substrate (15); and
  - 10 - at least a lever arm (26) extending at about tangentially from distal end of said stem (22), forming an elbow (28) thereat.
2. A microvalve according to Claim 1 wherein the cantilever structure (20) is fabricated to predetermined bending stiffness, anchor stiffness or rotational  
15 moment at at least one of said stem base (24) and elbow (28).
3. A microvalve according to Claim 1 wherein the cantilever structure (20) is normally in close position against one of said channels.
- 20 4. A microvalve according to Claim 3 wherein the cantilever structure (20) opens by fluid pressure exerting on at least one surface of the stem (22) or lever arm (26).
5. A microvalve according to Claim 1 wherein the cantilever structure (20)  
25 regulates fluid flow by deformation of at least one of its stem (22), elbow (28) and/or lever arm (26).
6. A microvalve according to Claim 5 wherein the deformation includes any one or combination of bending and/or rotation of the stem (22), elbow (28)  
30 and/or lever arm (26).

7. A microvalve according to Claim 5 wherein the fluid flow regulation by deformation of at least part of the cantilever structure (20) includes deflection to an extent in which the tip (27) of at least one of the lever arm (26) or elbow (28) touches an opposing surface (29) of a channel thereby directing fluid flow in a predetermined direction and avoiding dead volume.
8. A microvalve according to Claim 1 wherein the cantilever structure comprises any one of L-shape (20) or T-shape (30) structure formed via surface micromachining processes.
9. A microvalve according to Claim 1 wherein the lever arm (26) of the L-shape structure or lever arms (36, 37) of T-shape structure (30) extends to at least 40% of the length of the stem (27).
10. A microvalve according to Claim 8 wherein the base of the cantilever structure's stem (24) is constrained rigidly on a silicon substrate (15).
11. A microvalve according to Claim 10 wherein the silicon substrate (15) comprises silicon nitride ( $\text{Si}_3\text{N}_4$ ) (13) layer on silicon wafer (11).
12. A microvalve according to Claim 1 wherein the cantilever structure (20) is disposed in the semiconductor-fabricated body (10) as valve control over 2 fluid flow channels, including a first inlet channel (12) to a first outlet channel (14) and a second inlet channel (16) to a second outlet channel (18).
13. A microvalve according to Claim 12 wherein the cantilever structure (20) is deformable to simultaneously actuate valve control over said both fluid flow channels.

14. A microvalve according to Claim 1 wherein the cantilever structure (20) is deformable such that a tip (27) of the extended lever arm (26) is used to crimp or bend a flexible nanotube forming said fluid flow channel.

15. A method for fabricating a microvalve according to any one of Claims 1 – 14 with surface micromachining including the steps of:

- (a) depositing a layer of silicon nitride ( $\text{Si}_3\text{N}_4$ ) (13) on a silicon wafer (11);
- (b) depositing or growing and forming a pattern of sacrificial oxide layer;
- (c) depositing a polysilicon layer over the patterned sacrificial formed in step (b) above;
- (d) patterning said polysilicon layer to form a cantilever valve structure; and
- (e) removing said sacrificial oxide layer.

16. A method for fabricating a microvalve according to Claim 15 wherein the sacrificial oxide layer is phosphosilicate glass (PSG).

17. A method for fabricating a microvalve according to Claim 15 wherein the removal of the sacrificial oxide layer in step (e) involves buffer oxide etching (BOE).

18. A semiconductor device incorporating a microvalve according to any one of Claims 1 – 14.

19. A device or appliance incorporating a microvalve according to any one of Claims 1 – 14.

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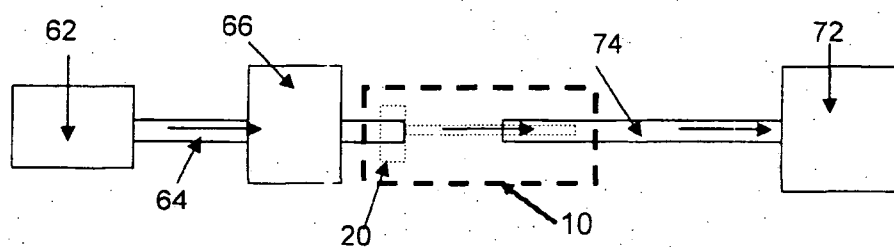


FIGURE 1

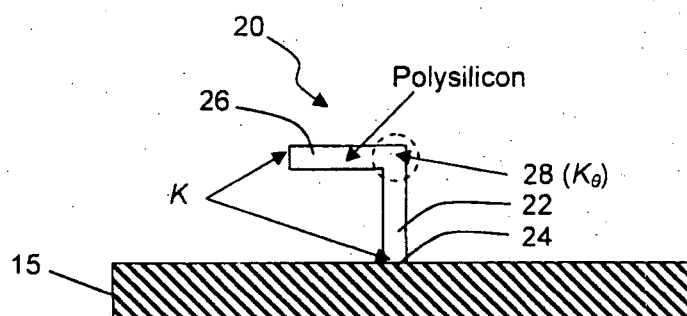


FIGURE 2

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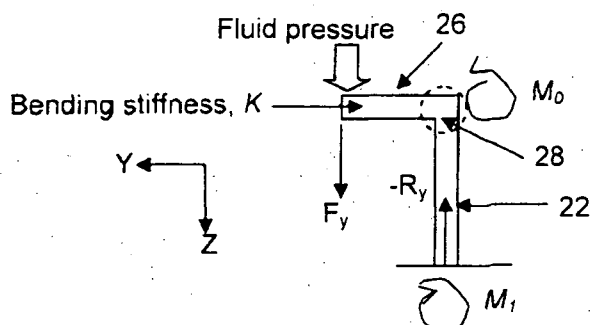


FIGURE 3

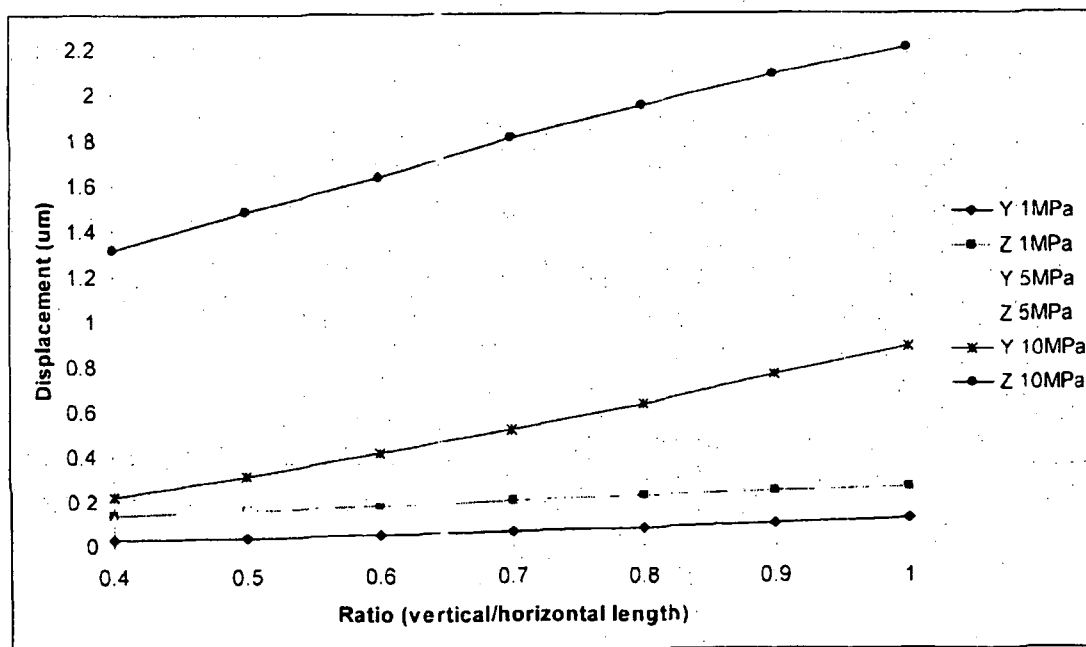


FIGURE 4

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FIGURE 5



FIGURE 6

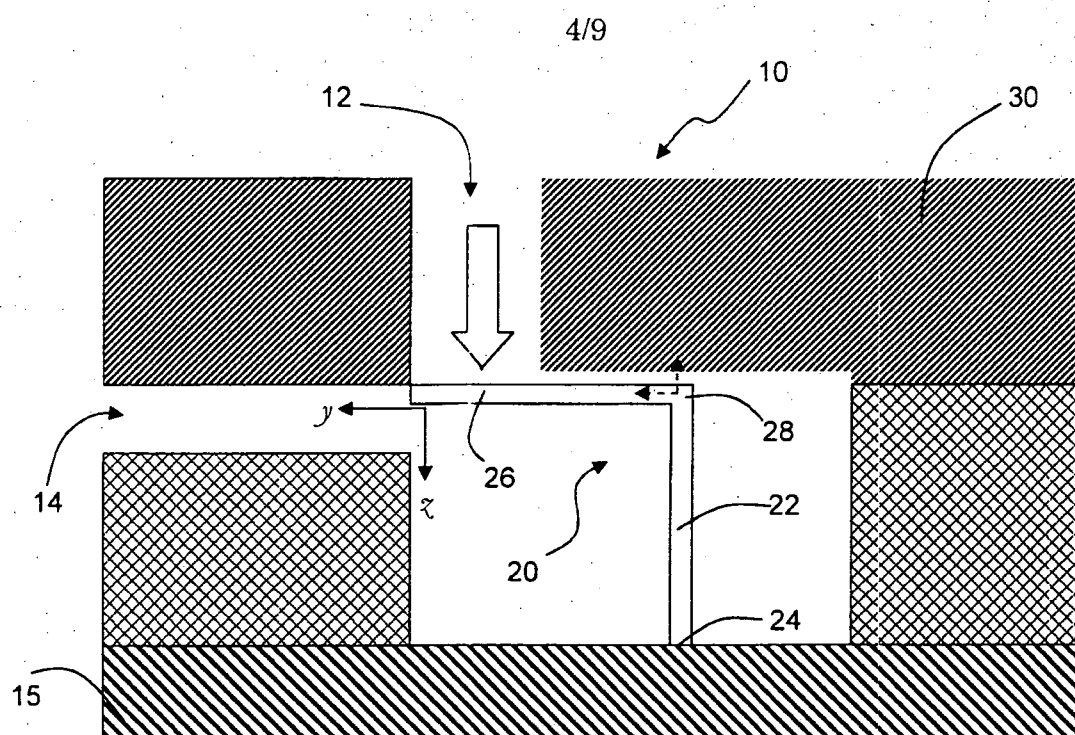


FIGURE 7

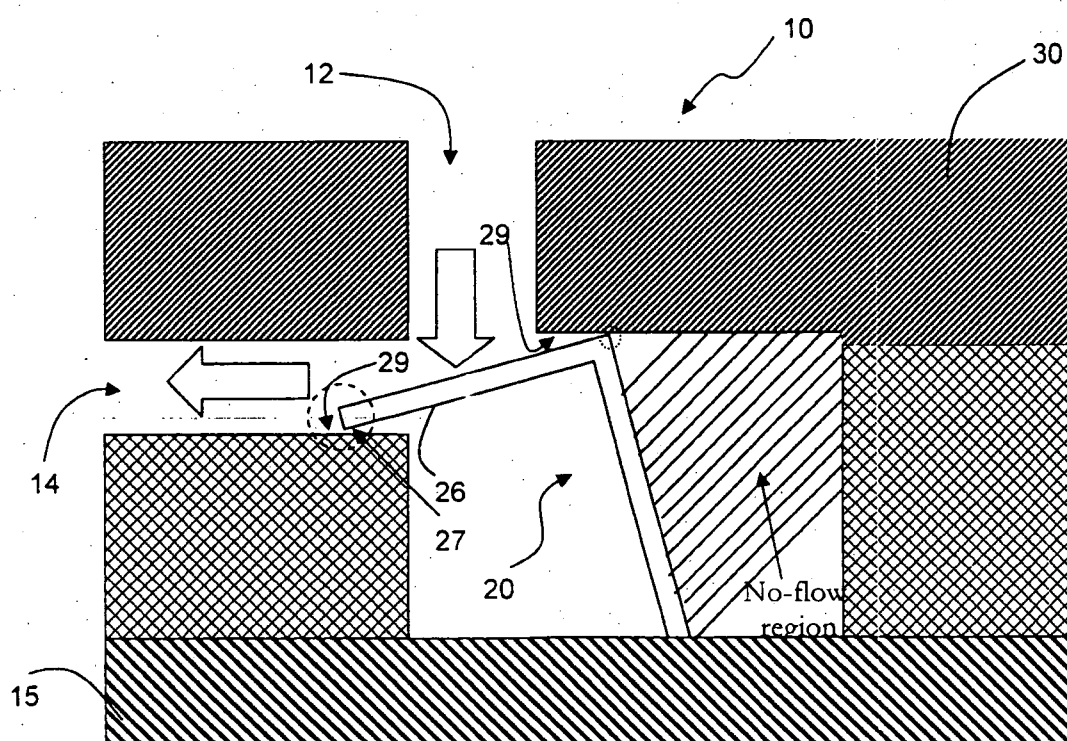


FIGURE 8

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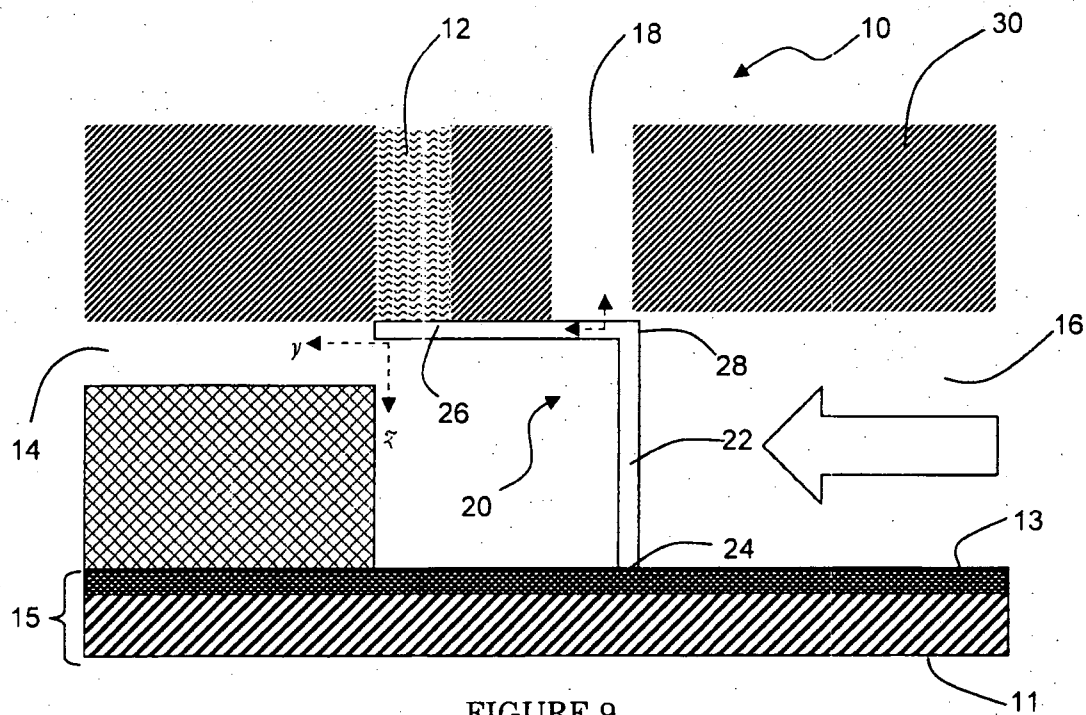


FIGURE 9

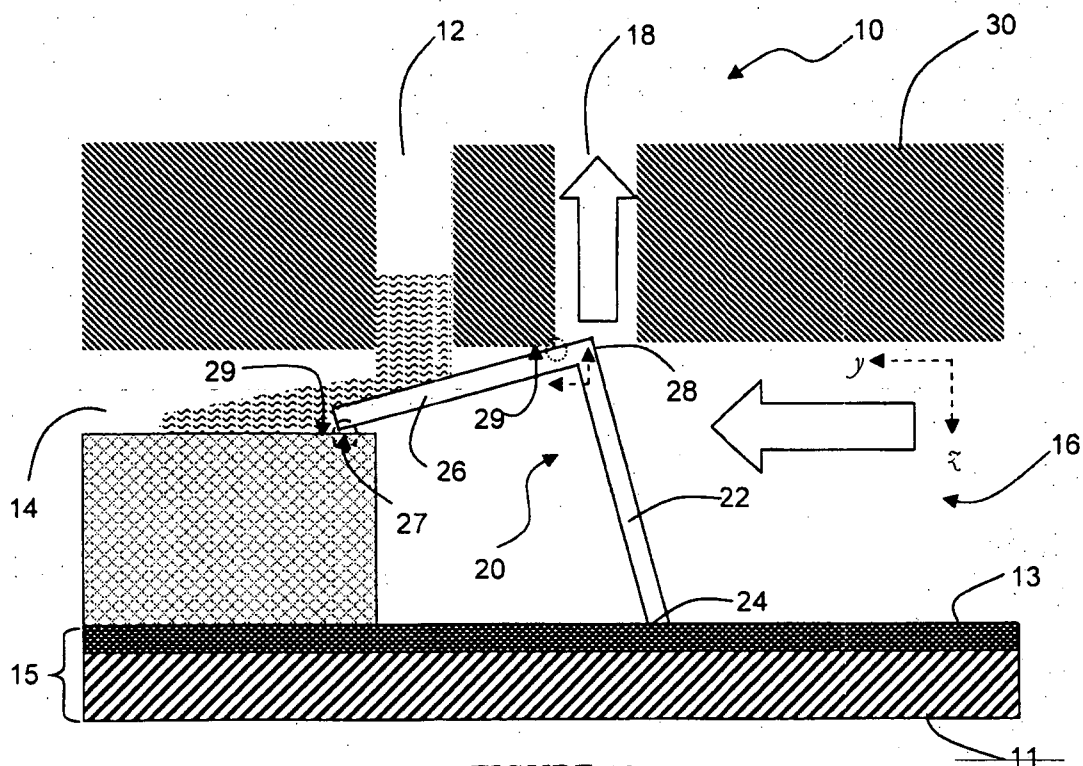


FIGURE 10

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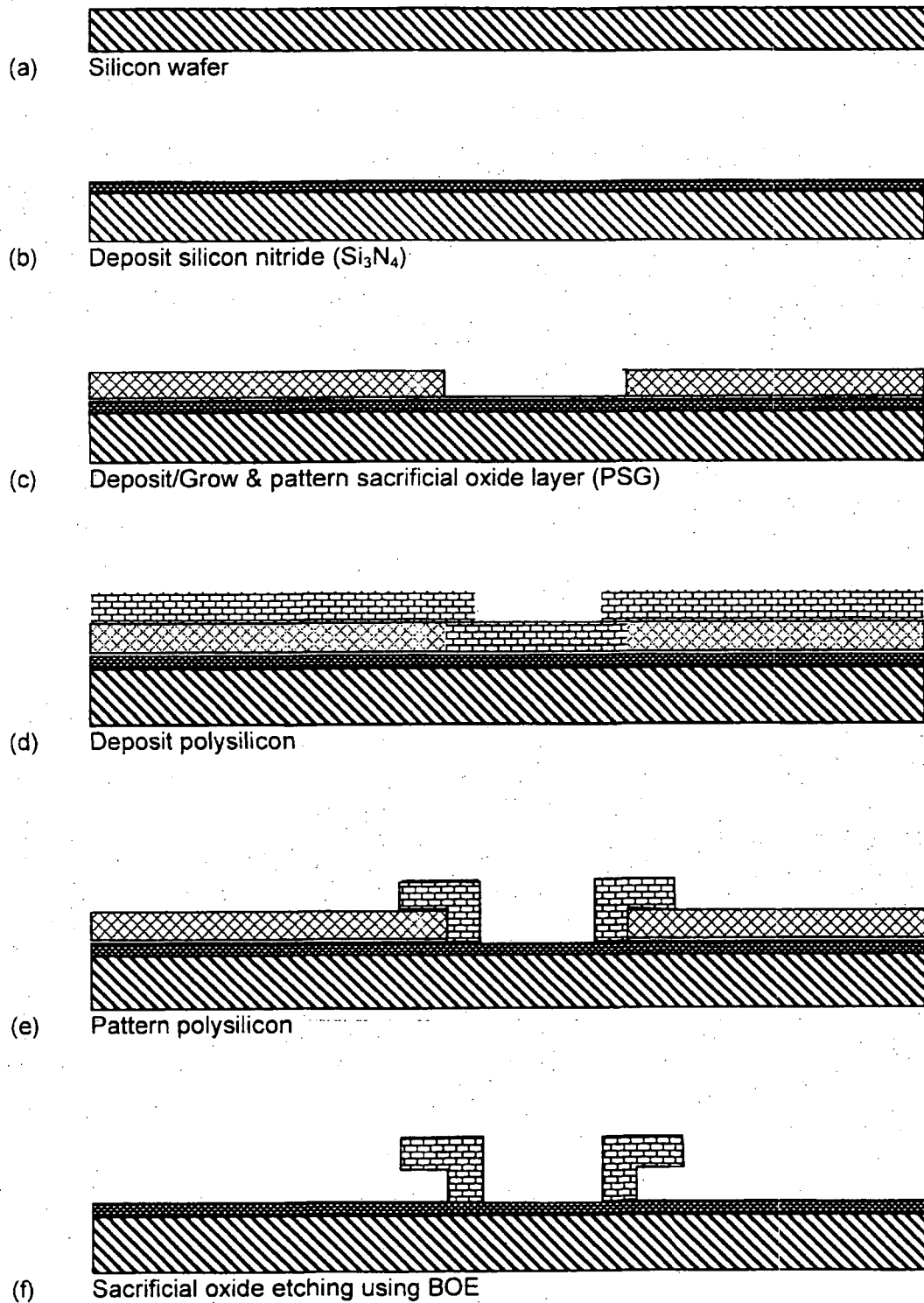


FIGURE 11

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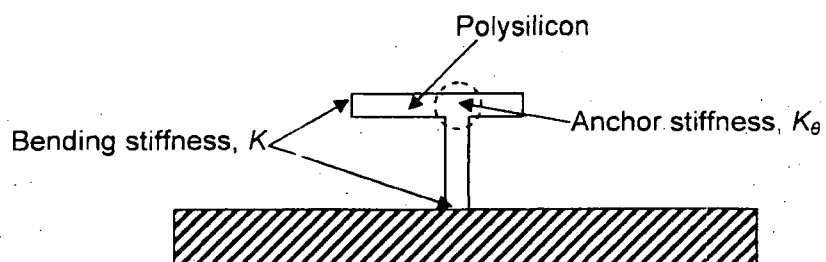


FIGURE 12

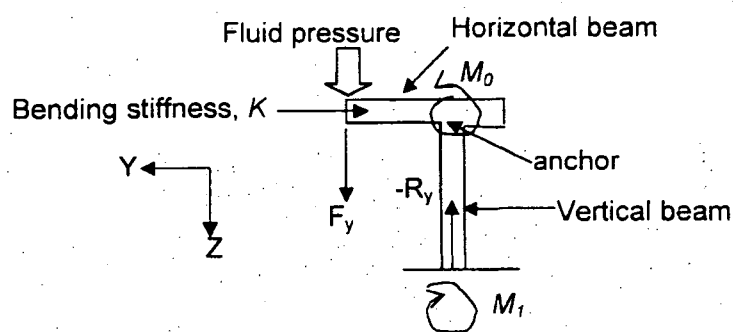


FIGURE 13

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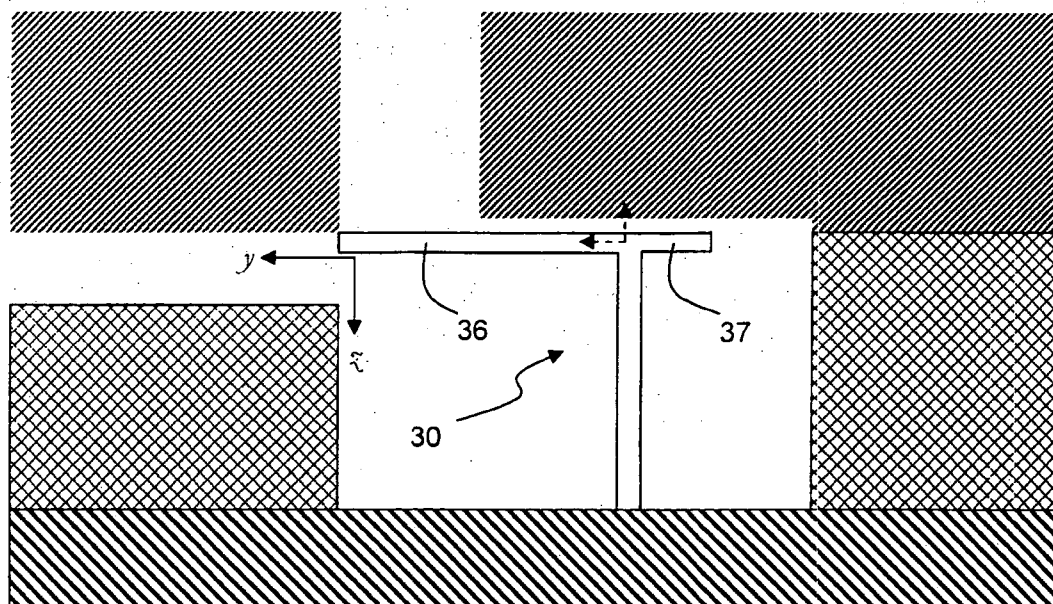


FIGURE 14

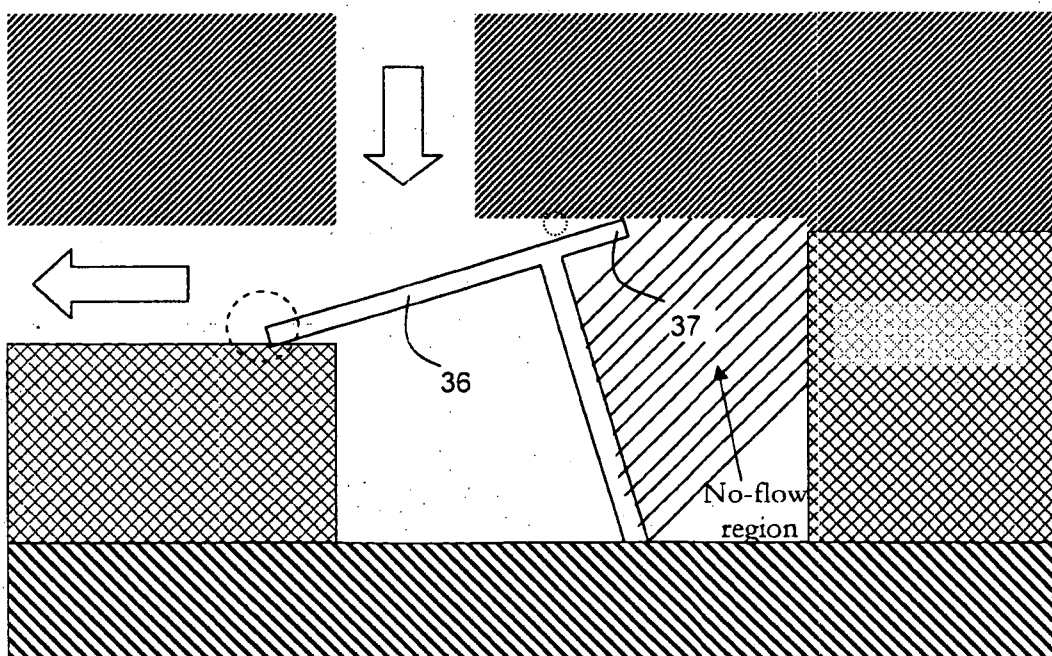


FIGURE 15

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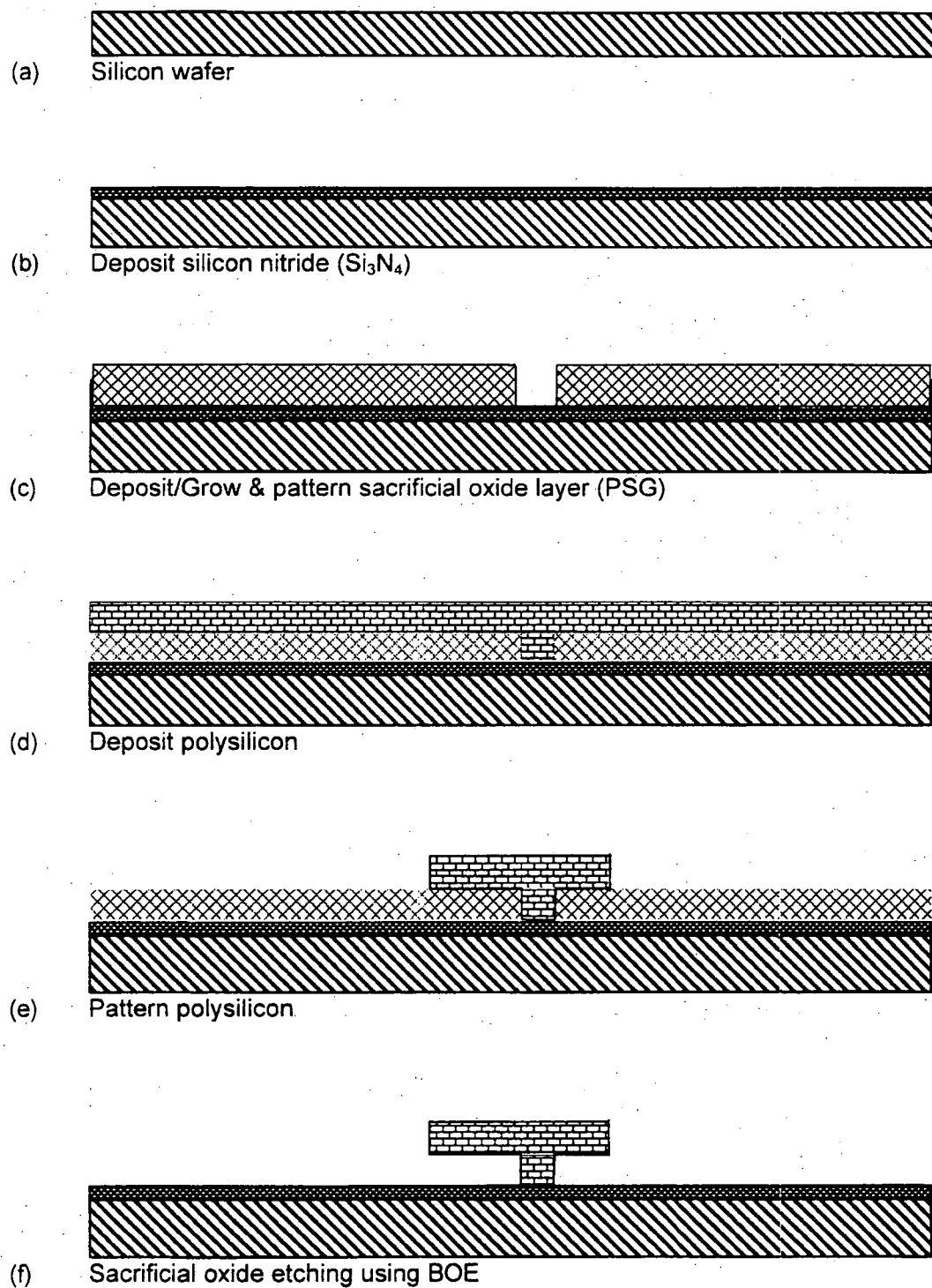


FIGURE 16

# INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/MY2010/000117**

## A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

**B81B 5/00** (2006.01)      **B81B 3/00** (2006.01)      **H01L 21/00** (2006.01)  
**B01L 99/00** (2010.01)      **F16K 99/00** (2006.01)

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)

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 practicable, search terms used)  
EPODOC, WPI, INSPEC: microvalve, microactuator, arm, elbow, stem, bend flex, cantilever, beam, flap, passive, pressure activated and similar terms

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                             | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | YANG, B., et al "A planar compliance-based self-adaptive microfluid variable resistor", Journal of Microelectromechanical Systems, April 2007, vol 16, no 2, pages 411-419.<br>The abstract, page 412 section "II DESIGN AND FABRICATION" and figures 1 and 2. |                       |
| A         | US 2003/0071235 A1 (GAMBLE ET AL) 17 April 2003.<br>Paragraphs [0008] to [0015] and figures 3(a) and 3(b).                                                                                                                                                     |                       |
| A         | WO 2004/061308 A1 (MOTOROLA INC) 22 July 2004.<br>The abstract, paragraphs [0005] and [0006] and figures 1 to 3.                                                                                                                                               |                       |
| A         | KWANG, W.Oh, et al "A review of microvalves" Journal of Micromechanics and Microengineering, 2006, volume 16, pages R13-R39.<br>Section 5.1 "Flap" and figure 14.                                                                                              |                       |



Further documents are listed in the continuation of Box C



See patent family annex

|                                                                                                                                                                         |                                                                                                                                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * Special categories of cited documents:                                                                                                                                |                                                                                                                                                                                                                                                  |
| "A" document defining the general state of the art which is not considered to be of particular relevance                                                                | "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention                                              |
| "E" earlier application or patent but published on or after the international filing date                                                                               | "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone                                                                     |
| "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| "O" document referring to an oral disclosure, use, exhibition or other means                                                                                            | "&" document member of the same patent family                                                                                                                                                                                                    |
| "P" document published prior to the international filing date but later than the priority date claimed                                                                  |                                                                                                                                                                                                                                                  |

Date of the actual completion of the international search  
**21 October 2010**

Date of mailing of the international search report  
**26 OCT 2010**

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/MY2010/000117

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

| Patent Document Cited in<br>Search Report                                                                                 |            |    |            | Patent Family Member |            |
|---------------------------------------------------------------------------------------------------------------------------|------------|----|------------|----------------------|------------|
| US                                                                                                                        | 2003071235 | EP | 1296067    | JP                   | 2003227572 |
| WO                                                                                                                        | 2004061308 | AU | 2003298633 | US                   | 2004120836 |
| Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001. |            |    |            |                      |            |
| END OF ANNEX                                                                                                              |            |    |            |                      |            |