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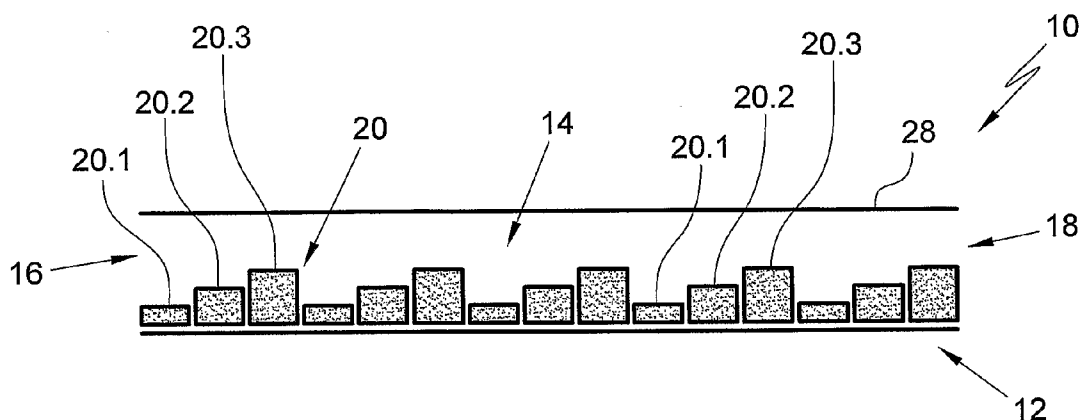
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(54) Title: A MICROFABRICATED DEVICE



(57) Abstract: A microfabricated device (10) includes a structure (12) defining a closed fluid delivery channel (14), the channel (14) having an inlet (16) and an opposed outlet (18). A conducting polymer actuator (20) is arranged within the fluid delivery channel (14). At least a part of the actuator (20) is configured to vary its cross sectional area in a direction transverse to a direction of fluid flow in the channel (14). An actuator control arrangement (22) is carried by the structure (12) for controlling the actuator (20) to cause the actuator (20) to expand and contract cyclically and sequentially along the length of the actuator (20) to vary the cross sectional area of the channel (14) cyclically and sequentially to effect a peristaltic pumping action to deliver fluid from the inlet (16) of the channel (14) to the outlet (18) of the channel (14).

"A microfabricated device"

Cross-Reference to Related Applications

The present application claims priority from Australian Provisional Patent Application No 2005904179 filed on 4 August 2005, the contents of which are
5 incorporated herein by reference.

Field of the Invention

This invention relates to a microfabricated device. The invention relates particularly, but not necessarily exclusively, to a microfabricated pumping device. The
10 microfabricated pumping device shall be referred to below as a "micropump".

Background to the Invention

The use of microfabricated devices for various applications is becoming increasingly prevalent. Such devices have found applications as pumps for controlled
15 release of drugs into a patient's body, as well as applications with microchips for microfluidics and analytics.

To provide control of the device, electrical devices are preferred and, generally, electrically powered pumps make use of actuators requiring voltages of the order of 10-100 volts such as, for example, piezoelectric actuators. Therefore, the devices need to
20 be made of materials having a dielectric strength which can withstand such voltages. This increases the bulk of the devices. Further, such devices may not be biocompatible and the voltage required does not make them suitable for implantation. Still further, the response time of such devices can, in certain circumstances, be inadequate.

Also, such pumps do not sufficiently accurately meter fluids in the microlitre, nanolitre or picolitre ranges which may be required for analytical purposes, medical
25 purposes or other purposes. A number of these pumps are also only operable unidirectionally.

Another type of device for use in the delivery of medication makes use of an osmotic infusion pump. Generally the output from such an infusion pump is essentially
30 constant and cannot be varied.

Summary of the Invention

According to the invention there is provided a microfabricated device which includes:

35 a structure defining a closed fluid delivery channel, the channel having an inlet and an opposed outlet;

a conducting polymer actuator arranged within the fluid delivery channel, at least a part of the actuator being configured to vary its cross sectional area in a direction transverse to a direction of fluid flow in the channel; and

an actuator control arrangement carried by the structure for controlling the actuator to cause the actuator to expand and contract cyclically and sequentially along the length of the actuator to vary the cross sectional area of the channel cyclically and sequentially to effect a peristaltic pumping action to deliver fluid from the inlet of the channel to the outlet of the channel.

By "closed fluid delivery channel" is meant that a part of the channel opposite the floor is covered by a cover member but the channel is open at its opposed ends.

The structure may include a base and a pair of spaced side walls extending upwardly from the base, the side walls supporting a cover layer spaced from the base to define the channel.

The structure may be formed by microfabrication techniques such as deposition and etching techniques. Thus, for example, the structure may be formed of silicon or any other suitably rigid material. A silicon structure has the advantage that interfacing with other control circuitry is facilitated. Instead, the structure may comprise a glass or other inert substrate on which the actuator control arrangement is deposited. The cover layer may be applied by micromachining techniques.

In one embodiment, the actuator may be arranged in the channel between the side walls. Thus, an entire width of the actuator may be able to have its cross sectional area varied. In another embodiment, the actuator may support the cover layer in a spaced position relative to the base, a central part of the actuator being configured to vary its cross sectional area while side parts of the actuator are fixed and non-varying and function as side walls to support the base and the cover member in spaced relationship.

The actuator may be a unitary, one-piece body or, instead, the actuator may be made up of a plurality of discrete actuator elements arranged in series in the channel. Where the actuator is a single body, adjacent parts of the body may be able to expand and contract independently of each other under the effect of the actuator control arrangement to create a peristaltic wave-like motion through the body from the inlet to the outlet. In the case where the actuator comprises a series of discrete actuator elements, the elements may be individually controlled by the actuator control arrangement to cause the peristaltic motion through the channel.

The actuator control arrangement may comprise an electrode array arrangement. The electrode array arrangement may comprise a plurality of electrode arrays to

facilitate phased cyclic expansion and contraction of the actuator elements to effect the peristaltic pumping action.

At least three electrode arrays may be provided to provide a three phase or higher phase actuation sequence to achieve directional flow of the fluid from the inlet
5 of the fluid delivery channel to the outlet of the fluid delivery channel.

In the case where three electrode arrays are used, a counter electrode arrangement may be provided. A counter electrode may be associated with each electrode array.

Instead, the electrode arrangement may comprise four electrode arrays arranged
10 in two pairs. With this arrangement, one of the electrode arrays of each pair may be used as a counter electrode for the other electrode array of that pair.

The electrode array arrangement may be deposited on the structure by an appropriate deposition technique, for example, by sputtering, printing, or the like.

The conducting polymer actuator elements (or conjugated polymers) have the
15 capability to be reversibly oxidised and reduced upon the application of a potential difference. The conducting polymers of the actuator may be selected from the group consisting of polypyrrole and its derivatives, polyaniline and its derivatives, polythiophene and its derivatives poly(ethylenedioxythiophene), polyphenylene, poly(pheylenevinylidene) and its derivatives, or the like.

It will be appreciated that, to effect expansion and contraction of the actuator
20 elements, the actuator elements need to be immersed in an electrolyte.

In one embodiment, a fluid to be pumped by the device is an electrolyte which reduces and oxidises the actuator, the actuator being exposed to the electrolyte in the channel. In another embodiment, a membrane may separate a fluid to be pumped
25 through the device and an electrolyte in which the actuator is immersed. The membrane may be a thin polymer membrane made of materials such as siloxane-based polymers, polyvinylchloride film, polyvinylidene fluoride, polyethylene, polypropylene, or other non-permeable membrane. Further, the membrane could be of a silicone material.

The electrolyte may be one of a liquid electrolyte, a polymer electrolyte, a
30 polymer gel electrolyte and an ionic liquid.

The liquid electrolytes are aqueous and organic based solvents, such as propylene carbonate, acetonitrile and gamma-butyrolactone. The liquid electrolytes may contain supporting salts with either anion or cations being able to move in and out
35 of the conducting polymer material. The salts may be low molecular salts selected from the group consisting of KCl, NaCl, KClO₄, tetrabutylammonium

hexafluorophosphate, tetrabutylammonium trifluoromethanesulfonate; surfactant type salts such as sodium dodecylsulphonate; polyelectrolytes ionic liquids, such as 1-butyl-3-methyl imidazolium tetrafluoroborate; or the like.

The polymer electrolytes and polymer gel electrolytes may be poly methyl methacrylate/lithium perchlorate in a propylene carbonate/acetonitrile mixture as a solvent.

The actuator may be grown on the actuator control arrangement via electropolymerisation techniques or deposited on the substrate surface.

10 **Brief Description of the Drawings**

Embodiments of the invention are now described by way of example with reference to the accompanying drawings in which:-

Fig. 1 shows a schematic, side view of a microfabricated device, in accordance with one embodiment of the invention;

15 Fig. 2 shows a schematic side view of a microfabricated device, in accordance with another embodiment of the invention;

Fig. 3 shows a schematic end view of the device of Fig. 1;

Fig. 4 shows a schematic plan view of an actuator control arrangement for the device of Fig. 1 or Fig. 2;

20 Fig. 5 shows a schematic side view of operation of the device of Fig. 1 using the actuator control arrangement of Fig. 4;

Fig. 6 shows a schematic plan view of a further actuator control arrangement;

Figs. 7A and 7B show two sequences of operation of the actuators using the control arrangement of Fig. 6;

25 Fig. 8 shows a schematic, side view of a microfabricated device, in accordance with another embodiment of the invention;

Fig. 9 shows a schematic, end view of a microfabricated device, in accordance with yet a further embodiment of the invention;

30 Fig. 10A shows, above, a three dimensional AFM topographic image and, below, a cross-sectional line drawing end view of a first polypyrrole actuating element prepared for experimental purposes; and

Fig. 10B shows, above, a three dimensional AFM topographic image and, below, a cross-sectional line drawing end view of a second polypyrrole actuating element prepared for experimental purposes.

Detailed Description of Exemplary Embodiments

In the drawings, reference numeral 10 generally designates a microfabricated device, in accordance with an embodiment of the invention. The device 10 includes a structure 12 defining a channel 14. The channel 14 has an inlet 16 and an opposed outlet 18. A plurality of conducting polymer actuator elements, or actuators, 20 is arranged in the channel 14 of the structure 12.

The device 10 includes an actuator control arrangement in the form of an electrode array arrangement 22 for controlling operation of the actuators 20, as will be described in greater detail below. One example of an electrode array arrangement 22 is shown in Fig. 4 of the drawings with another example of the electrode array arrangement 22 being shown in Fig. 6 of the drawings.

A particular application of the device 10 is as a micropump. The invention will be described with reference to that application below although it will readily be appreciated by those skilled in the art that the invention could be used in other applications. The micropump 10 is a miniature device having dimensions in the micrometre scale.

The structure 12 comprises a substrate 24 having a pair of opposed sidewalls 26 defining the channel 14. A sealing, or cover, layer 28 is mounted on the walls 26 to define a closed fluid delivery channel 14 (as defined).

The structure 12 is formed by any suitable microfabrication techniques such as, for example, deposition and etching techniques. Thus, the substrate 12 is a suitable material able to be deposited and etched such as silicon or any other suitable rigid material that allows for electrodeposition. An advantage of using silicon for the substrate 24 is its ability to interface electrically with other control circuitry.

The electrode array arrangement 22 can either be a three phase arrangement comprising three electrode arrays 30, 32 and 34 (Fig. 4) or a four electrode array arrangement comprising four electrode arrays 36, 38, 40 and 42 (Fig. 6). Regardless of the configuration of the electrode array arrangement 22, the electrode array arrangement 22 is deposited or otherwise applied to the substrate 24 in a suitable manner, for example, by sputtering, printing, or other suitable microfabrication techniques. It will be appreciated that the electrode arrays 30, 32 and 34 or 36-42 are electrically insulated from each other so that each array controls every third or fourth actuator 20, as the case may be.

Thus, each electrode array 30-42 is a substantially comb-like structure and has a conductive strip 44 with a plurality of conductor pads, or electrodes, 46 extending

orthogonally from the conductive strip 44. The conductor pads 46 are located on the base of the channel 14 and each conductor pad 46 has an actuator 20 associated with it.

In the three phase arrangement 22 shown in Fig. 4 of the drawings, each electrode array 30, 32, 34 may have a counter electrode (not shown) associated with it. However, if the phases are controlled appropriately, i.e. by being 120° out of phase with one another, any two electrodes can act as the counter electrode for the third electrode obviating the need for independent counter electrodes. In contrast, in the case of the electrode arrays 36-42 as shown in Fig. 6 of the drawings, the electrode arrays 36-42 are arranged in pairs so that one electrode array of each pair serves as a counter electrode for the other electrode array of the pair. Thus, because the electrode arrays 36 and 40 are 180° out of phase with each other, they form an electrode array pair with the electrode arrays 36 and 40 forming counter electrodes for each other. Similarly, the electrode arrays 38 and 42 are arranged in a counter electrode pair.

The actuators 20 are conjugated polymer actuators, such as polypyrrole actuators, which are grown on the conducting pads or electrodes 46 of the electrode arrays by electropolymerisation.

Because the actuators 20 are conducting polymer actuators, they require the presence of an electrolyte for expansion and contraction, i.e., oxidation and reduction. In the embodiment shown in Fig. 1 of the drawings, it is assumed that the fluid to be pumped is the electrolyte and the actuators 20 are in direct contact with the fluid in the channel 14. In the embodiment shown in Fig. 2 of the drawings, it is assumed that the fluid to be pumped is not a suitable electrolyte. In that case, the channel 14 is separated into two zones, a pumping zone 14.1 and an actuator zone 14.2, by a membrane 48. The membrane 48 is of any suitable material such as a thin, polymer material. The polymer material is a siloxane-based polymer, polyvinylidene fluoride, polyethylene, polypropylene, or the like. The membrane 48 is applied via suitable microfabrication techniques, such as, for example, deposition and etching techniques.

The electrolyte is chosen from liquid electrolytes, polymer electrolytes, polymer gel electrolytes and ionic liquids. The liquid electrolytes are aqueous and organic solvent based. They contain supporting salts with either anions or cations being able to move in and out of the material of the polymer actuators 20. The salts are chosen from any suitable salt such as a low molecular salt, for example, KCl, KClO_4 , TBAPF_6 , $\text{TBACF}_3\text{SO}_3$, or the like; surfactant type salts, for example dodecylbenzenesulphonate or alkyl sulphonates, polyelectrolytes, for example, polystyrenesulphonate or polyacrylic acid, and ionic liquids, for example, 1-butyl-3-methyl imidazolium tetrafluoroborate.

Polymer electrolytes and polymer gel electrolytes are selected from suitable polymer electrolytes such as poly(methyl methacrylate)/LiClO₄ in propylene carbonate/acetonitrile mixture as a solvent.

The polymer of the actuators and the small size of the actuators 20, having a height in the order of 1 μ m to a few μ m's, is exploited to achieve high speed operation of the micropump 10 and high density of actuators 20 on the substrate. Conducting polymers have large strains/deformations in comparison with actuators in piezoelectric devices. These large strains/deformations offer significant advantages. However, whilst polymer actuators with strains/deformations of more than 20% are preferred, devices of the invention are still practical with lower strains/deformations, just requiring higher or deeper actuating elements. The actuators 20 also have fast actuation, in the order of 1Hz. In addition, the channel 14 is designed to have a small fluid channel cross-section relative to the width of the actuators 20 in order to exploit hydraulic viscosity to improve hydrostatic pressures. With this configuration, the micropump 10 is able to operate without any valves.

The small channel 14 in combination with rapid actuation of the actuators 20 ensures that viscous effects of the fluid being pumped assists in avoiding backflow of the pumped fluid even in the presence of an adverse pressure gradient. The viscous effects of the fluid being pumped cause a dynamic seal between the top of the actuators and the sealing layer 28 and around the sides of the actuators 20 and the internal surfaces of the walls 36 of the structure 12 due to fluid friction and inertia. In addition, a further consequence of the small fluid channel 14 is the presence of a small dead volume with capillary effects being exploited to make the pump 10 self-priming.

Referring now to the electrode arrangement 22 shown in Fig. 4 and the actuators of Fig. 5, three separately controllable electrode arrays 30, 32, 34 are provided so that every third actuator 20 moves in phase. Thus, as shown in Fig. 1 of the drawings, the actuators 20.1 move in phase with each other, the actuators 20.2 move in phase with each other and the actuators 20.3 move in phase with each other. A similar arrangement applies with respect to the embodiment of the micropump 10 shown in Fig. 2 of the drawings where the actuators 20 act on the membrane 48. In both embodiments, appropriate control of the actuators 20 in a cyclic and sequential manner causes a peristaltic pumping action from the inlet 16 to the outlet 18 of the channel 14. Thus, by introducing an appropriate phase delay (120° in the case of the electrode array arrangement 22 of Fig. 4) between adjacent actuators 20.1 and 20.2, 20.2 and 20.3 and 20.3 and 20.1, directional fluid motion in a direction of arrow 50 (Fig. 5) and a driving pressure gradient is achieved. In Fig. 5, actuator motion is shown by the arrows 52.

The pressure gradient can be increased by increasing the number of groups of actuators 20 (i.e. the number of units of 3 or 4 actuators) along the array arrangement 22 between the inlet 16 and the outlet 18. As a general rule, the total pressure difference will increase with an increasing number of recurrent actuator groups used, all other parameters being kept constant.

As previously indicated, with the electrode arrangement 22 of Fig. 4 of the drawings, any two electrodes may act as counter electrodes for the third electrode providing that there is no phase error, or each electrode array 30, 32, 34 may have a counter electrode associated with it. Thus, as an actuator 20 is reduced or oxidised opposite charge movement of equal magnitude occurs at a counter electrode.

Referring to the embodiment of the invention shown in Figs. 6 and 7 of the drawings, with the provision of four electrode arrays 36-42 adjacent actuators 20 are always 90° out of phase with each other. Hence a travelling peristaltic "wave" motion can be generated as shown in the two sequences in Fig. 7 of the drawings. Once again, arrows 52 indicate direction of actuator movement. Also, as previously described, with the electrode arrangement of Fig. 6, the electrode array pairs serve as counter electrodes for each other and the need for further counter electrodes is obviated.

Referring now to Fig. 8 of the drawings, another embodiment of the micropump 10 is shown. With reference to the previous drawings, like reference numerals refer to like parts unless otherwise specified.

In this embodiment, the actuator is comprised of a single or unitary body 60 arranged in the channel 14. The electrolyte is contained in the body 60 or some external reservoir in communication with the body. Adjacent parts of the body are individually addressable by the electrode array arrangement 22 to cause the parts of the body 60 to oxidise and reduce independently of each other as electrolyte is absorbed or expelled, as the case may be. As a result, by appropriate control of the body 60, a peristaltic wave-like motion is imparted to the body to drive fluid through the channel from the inlet 16 to the outlet 18.

In Fig. 9 of the drawings, yet a further embodiment of the micropump 10 is illustrated. Once again, with reference to the previous drawings, like reference numerals refer to like parts unless otherwise specified.

The substrate 24 of the structure 12 and the cover layer 28 are separated from each other by a conjugated polymer actuator 70 interposed between the substrate 24 and the cover layer 28. When viewed from the end, the actuator 70 has a central part 72 that is responsive to electric fields generated by the electrode array arrangement 22. In contrast, side parts 74 of the actuator 70 are not responsive to the electric fields. The

side parts 74 of the actuator 70 therefore serve as side walls to support the cover layer 28 in spaced relationship relative to the substrate 24. When an electric field is applied to the actuator 70 the central part 72 is reduced causing a channel 76 to open as shown in dotted lines. By cyclically and sequentially energising the central part 72 of the
5 actuator 70, a peristaltic wave-like motion is generated to cause fluid flow from the inlet 16 to the outlet 18 of the micropump 10.

It will be appreciated that the actuator 70 could be implemented either as a single body, as described above with reference to the previous embodiment, or it could be implemented as a series of discrete actuators such as the actuators 20 of the
10 embodiment described with reference to Figs. 1-7 of the drawings. Optionally, a membrane is interposed on that surface of the actuator 70 which is displaced, normally the surface facing an inner surface of the cover layer 28. The membrane serves to inhibit leakage of fluid through sides of the actuator 70. The membrane may be bonded to the surface of the actuator 70. The membrane could be preformed to form the
15 channel 76 with the actuator 70 being activated to compress the membrane to reduce the channel 76 to achieve the peristaltic pumping action.

Set out below are two examples of the preparation of polypyrrole (PPy) actuating elements suitable for use in the device 10.

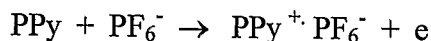
20 Example 1

Figure 10A shows a polypyrrole (PPy) actuating element 80. In Fig. 10A, the upper illustration shows a three dimensional atomic force microscopy (AFM) topographic image of the polypyrrole (PPy) actuating element 80 and the lower illustration shows a cross-sectional line drawing end view of the polypyrrole (PPy)
25 actuating element 80.

To form the element 80, polypyrrole (PPy) was deposited potentiostatically at 0.85 V against Ag/AgCl on patterned parallel gold strips (not shown) on a chip-like substrate on a 1.5 cm x 1.5 cm glass plate (not shown) using a common connector for the working electrodes. The deposition solution was 0.1 M pyrrole and 0.1 M
30 tetrabutylammonium hexafluorophosphate (TBAPF₆) in propylene carbonate (PC). The electrochemical polymerization was stopped once the consumed charge reached 1 mC (for a working electrode area of 0.024 cm²), to obtain a film thickness of about 2 μm. The PPy elements 80 were cycled in pyrrole-free solution of 0.1 M TBAPF₆ in propylene carbonate. The alternative strips were then oxidized and reduced at a
35 constant potential of +1 V or -1 V for approximately 3 minutes. After the oxidation/reduction step, the chip was taken out of the electrolyte solution, patted

briefly to remove the electrolyte solution from the surface and measured by AFM (Nanoscope II). The section analysis measurements were performed on at least 5 different positions.

When the PPy/ PF₆ elements 80 were oxidized at +1V the oxidation caused an expansion of the film while reduction at the adjacent electrode caused a shrinkage as illustrated in Fig. 10A. In Fig. 10A, a PPy strip 82 to the left of a channel 84 was reduced at -1 V and a PPy strip 86 to the right of the channel 84 was oxidized at +1 V. The difference in the height of oxidized and reduced PPy elements was $66 \pm 4 \%$. On oxidation positive charges (polarons and bipolarons) were created on the polymer backbone and PF₆⁻ anions and accompanying solvent entered the PPy elements 80 to balance the positive charges on the polymer and, as a result, the polymer expanded considerably arising from the following:

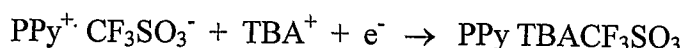


Example 2

Figure 10B shows a second polypyrrole (PPy) actuating element 80. With reference to Fig. 10A, like reference numerals refer to like parts unless otherwise specified. Once again, in Fig. 10B, the upper illustration shows a three dimensional atomic force microscopy (AFM) topographic image of the polypyrrole (PPy) actuating element 80 and the lower illustration shows a cross-sectional line drawing end view of the polypyrrole (PPy) actuating element 80.

The experiment was performed similarly to Example 1 above except that tetrabutylammonium trifluoromethanesulfonate (TBACF₃SO₃) was used as an electrolyte both for polymerisation and actuation. The AFM topographic image shows that, in this case, the PPy strip 82 oxidized at +1V (to the left of the channel 84) shrank and the PPy strip 86 reduced at -1 V (to the right of the channel 84) expanded, which is opposite to Example 1. The section analysis showed that the average height change between 1.0 V and -1.0 V was $47 \pm 10\%$.

The reduced state displayed a larger volume due to a cation insertion process caused by large CF₃SO₃⁻ anions being immobilized deep within the polymer structure during electropolymerisation. As the polymer is reduced and positive charges removed from the polymer, TBA⁺ cations and solvent need to move in to the film to balance the negative charge of the residual CF₃SO₃⁻ ions as shown by the following:



This results in film swelling.

Examples 1 and 2 demonstrate that both anion and cation movement can be used
5 for the actuation of PPy actuating elements depending on the choice of electrolyte used during the polymer synthesis and actuation.

Hence, by means of the invention, a micropump 10 is provided which can be accurately controlled electrically, has actuators 20 which exhibit large strains, i.e.
10 deformation of the actuators 20, and requires low voltage to operate, the applied voltage being of the order of about 1 volt. As a result, the micropump 10 can be manufactured from very small components and the dielectric strength of the material need not be selected to withstand high voltages. In addition, the micropump 10 can be made from or encapsulated in biocompatible materials for implantation in the human
15 body to be used for controlled released drug delivery or related applications. The micropump 10 can also be used in microfluidic applications and "lab-on-a-chip" applications. Still further, the micropump 10 can be used in analytic devices and portable desalination systems.

It is an advantage of the invention that a micropump 10 is provided which, being
20 of all solid-state fabrication, can be manufactured by micromachining techniques, including, for example, photolithography. It is of compact dimensions and lightweight. Further, as indicated above, the micropump 10 can be of a biocompatible material or encapsulated in a biocompatible material for implantation purposes. Due to the fact that non-metallic components are used, the need for biocompatible metallic
25 components, such as titanium components, is obviated. In addition, the micropump 10 has no mechanically moving parts and, as a result, should be able to operate over long periods of time. Related to this is the fact that no valves are required thereby further improving the wear resistance of the micropump 10. The micropump 10 can also be used in a bi-directional manner by appropriate actuation of the actuators 20.

30 The micropump 10 is a small volume device enabling metering of fluids in the picolitre, nanolitre and microlitre ranges and is able to be implanted into patients for controlled released drug delivery.

The use of conducting polymers as actuators enables large strains/deformations at low voltages in comparison with piezoelectric devices, which carries the benefit of
35 reducing the overall height of the device. Further, the use of polymers simplifies

manufacture and results in a relatively inexpensive, disposable device which is also less fragile than existing micropumps.

The use of a silicon substrate 24 for the structure 12 renders the micropump 10 suitable for interconnection with control circuitry to enable the micropump 10 to be controlled, possibly externally of the patient's body, by suitable wireless interfaces. The micropump 10 can also be integrated with a microprocessor to provide refined control of drug delivery. Hence dosages can be altered externally of the patient's body by means of the processor and the wireless interface.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

CLAIMS:

1. A microfabricated device which includes:
a structure defining a closed fluid delivery channel, the channel having an inlet and an opposed outlet;
- 5 a conducting polymer actuator arranged within the fluid delivery channel, at least a part of the actuator being configured to vary its cross sectional area in a direction transverse to a direction of fluid flow in the channel; and
an actuator control arrangement carried by the structure for controlling the actuator to cause the actuator to expand and contract cyclically and sequentially along
10 the length of the actuator to vary the cross sectional area of the channel cyclically and sequentially to effect a peristaltic pumping action to deliver fluid from the inlet of the channel to the outlet of the channel.
2. The device of claim 1 in which the structure includes a base and a pair of spaced
15 side walls extending upwardly from the base, the side walls supporting a cover layer spaced from the base to define the channel.
3. The device of claim 2 in which the cover layer is applied by micromachining techniques.
20
4. The device of claim 2 or claim 3 in which the actuator is arranged in the channel between the side walls.
5. The device of claim 2 or claim 3 in which the actuator supports the cover layer
25 in a spaced position relative to the base, a central part of the actuator being configured to vary its cross sectional area while side parts of the actuator function as side walls to support the base and the cover member in spaced relationship.
6. The device of any one of the preceding claims in which the actuator is a unitary,
30 one-piece body.
7. The device of any one of claims 1 to 5 in which the actuator is made up of a plurality of discrete actuator elements arranged in series in the channel.
- 35 8. The device of any one of the preceding claims in which the actuator control arrangement comprises an electrode array arrangement.

9. The device of claim 8 in which the electrode array arrangement comprises a plurality of electrode arrays to facilitate phased cyclic expansion and contraction of the actuator elements to effect the peristaltic pumping action.
- 5 10. The device of claim 8 or claim 9 in which the electrode array arrangement is deposited on the structure by a deposition technique
- 10 11. The device of any one of the preceding claims in which conducting polymers of the actuator are selected from the group consisting of polypyrrole and its derivatives, polyaniline and its derivatives, polythiophene and its derivatives poly(ethylenedioxythiophene), polyphenylene, poly(pheylenevinylidene) and its derivatives.
- 15 12. The device of any one of the preceding claims in which a fluid to be pumped by the device is an electrolyte which reduces and oxidises the actuator, the actuator being exposed to the electrolyte in the channel.
- 20 13. The device of any one of claims 1 to 11 in which a membrane separates a fluid to be pumped through the device and an electrolyte in which the actuator is immersed.
14. The device of claim 13 in which the membrane is a polymer membrane.
15. The device of any one of claims 12 to 14 in which the electrolyte is one of a liquid electrolyte, a polymer electrolyte, a polymer gel electrolyte and an ionic liquid.
- 25 16. The device of claim 15 in which the liquid electrolytes are aqueous and organic based solvents.
- 30 17. The device of claim 16 in which the liquid electrolytes contain supporting salts with either anion or cations being able to move in and out of the conducting polymer material.
18. The device of claim 17 in which the salts are low molecular salts selected from the group consisting of KCl, NaCl, KClO₄, tetrabutylammonium hexafluorophosphate, 35 tetrabutylammonium trifluoromethanesulfonate.

19. The device of claim 17 in which the salts are surfactant type salts.
20. The device of claim 17 in which the salts are polyelectrolyte ionic liquids.
- 5 21. The device of claim 15 in which the polymer electrolytes and polymer gel electrolytes are poly methyl methacrylate/lithium perchlorate in a propylene carbonate/acetonitrile mixture as a solvent.
- 10 22. The device of any one of the preceding claims in which the actuator is grown on the actuator control arrangement via electropolymerisation techniques or deposited on the substrate surface.

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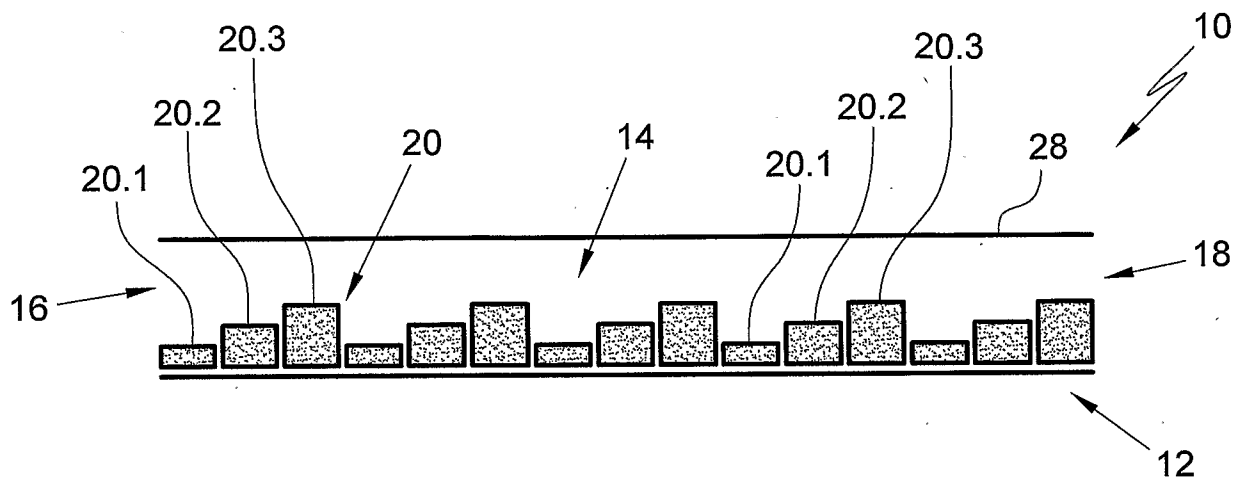


Fig. 1

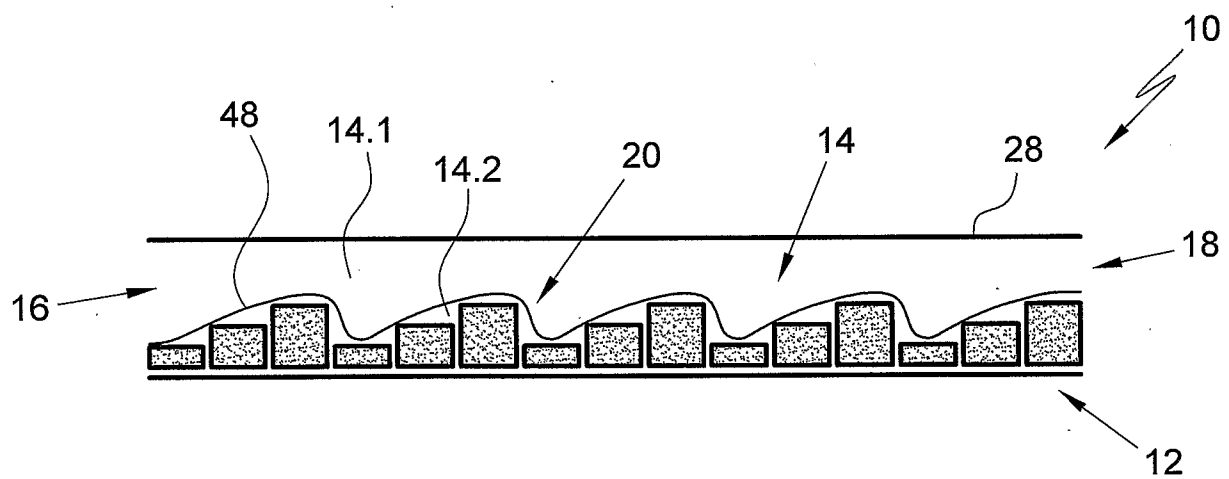


Fig. 2

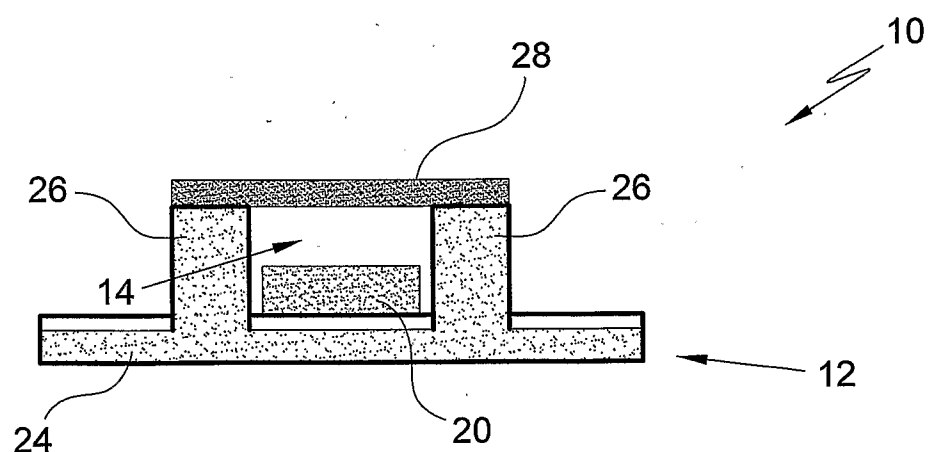


Fig. 3

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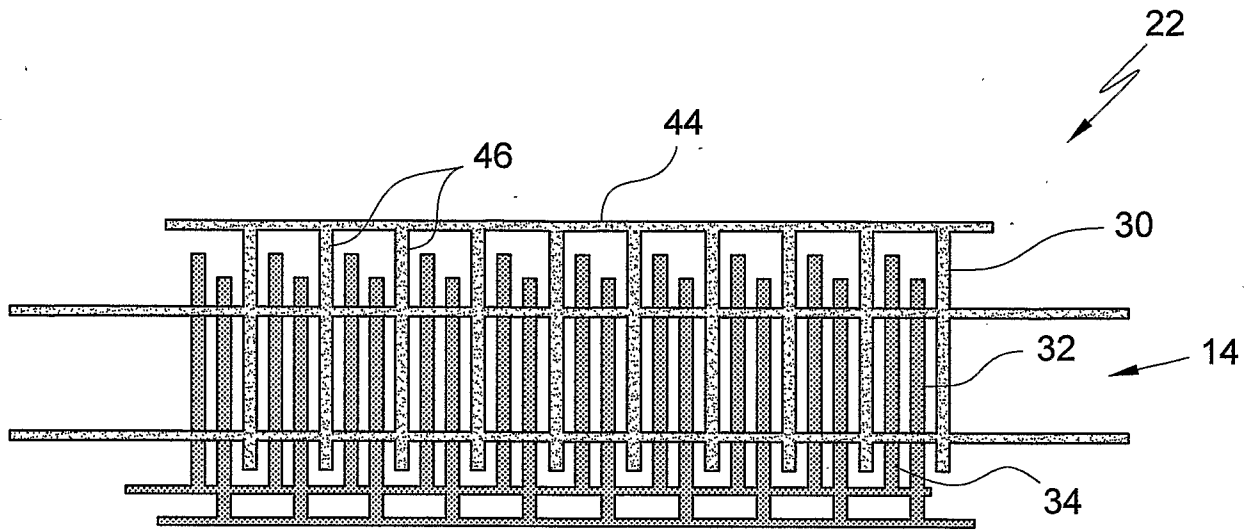


Fig. 4

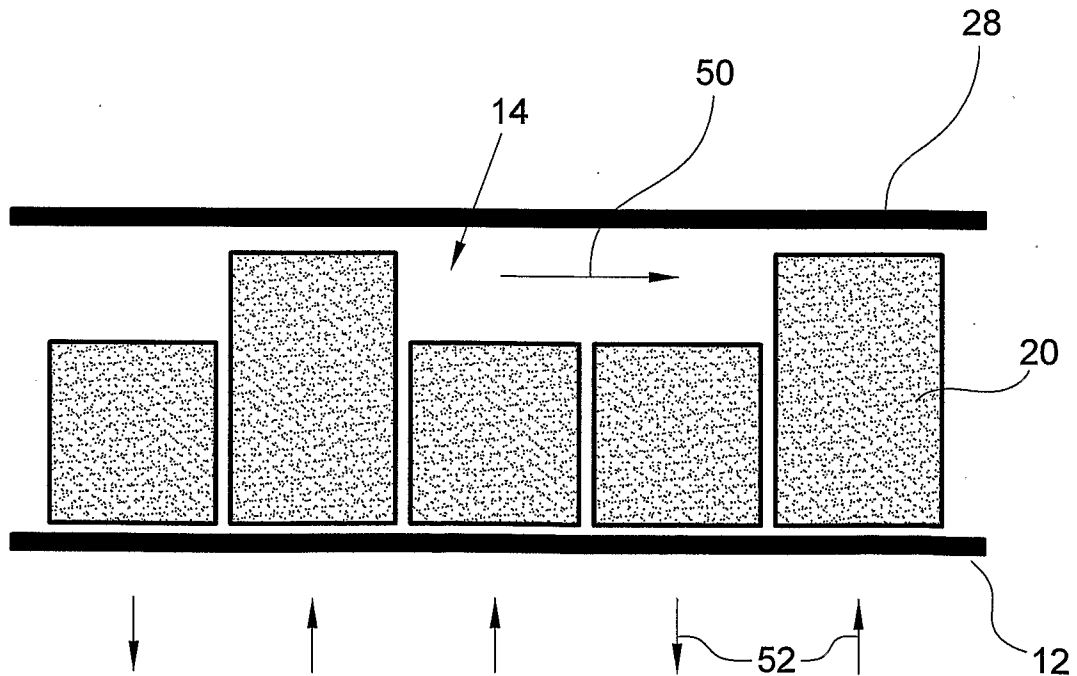


Fig. 5

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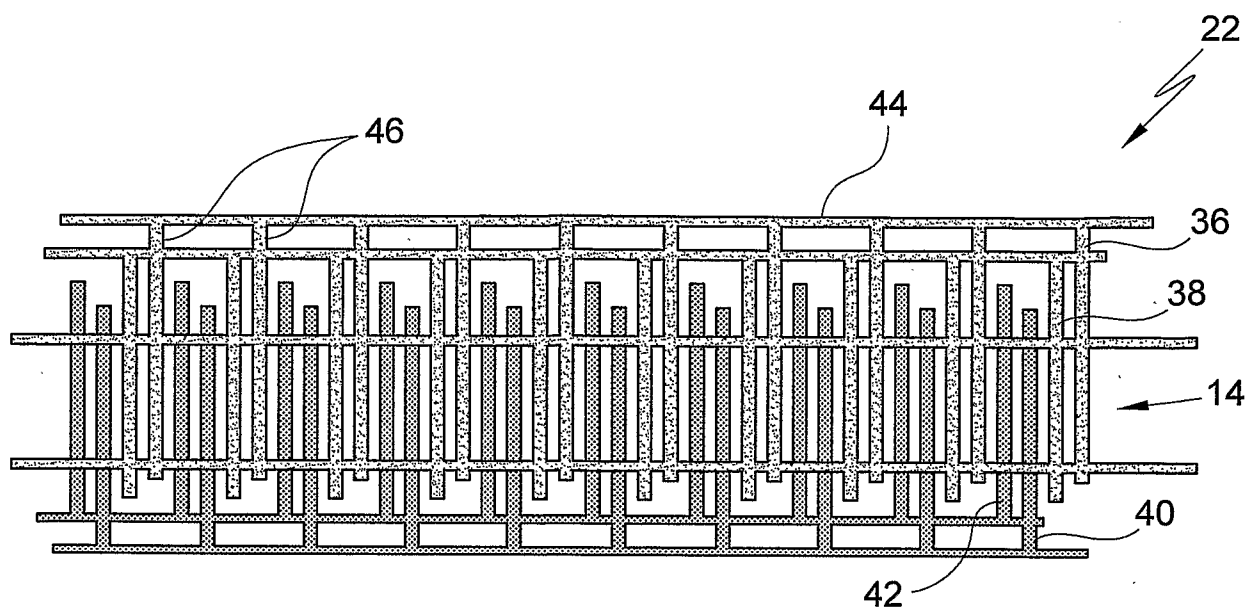


Fig. 6

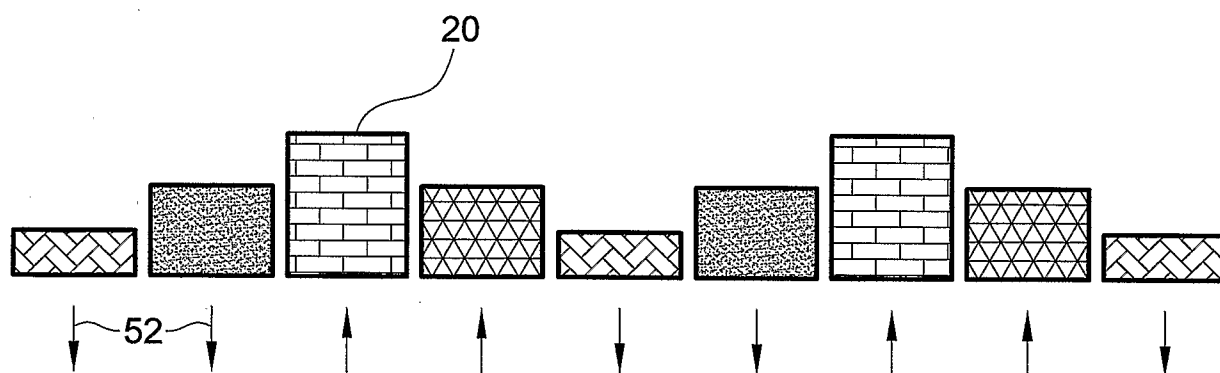


Fig. 7a

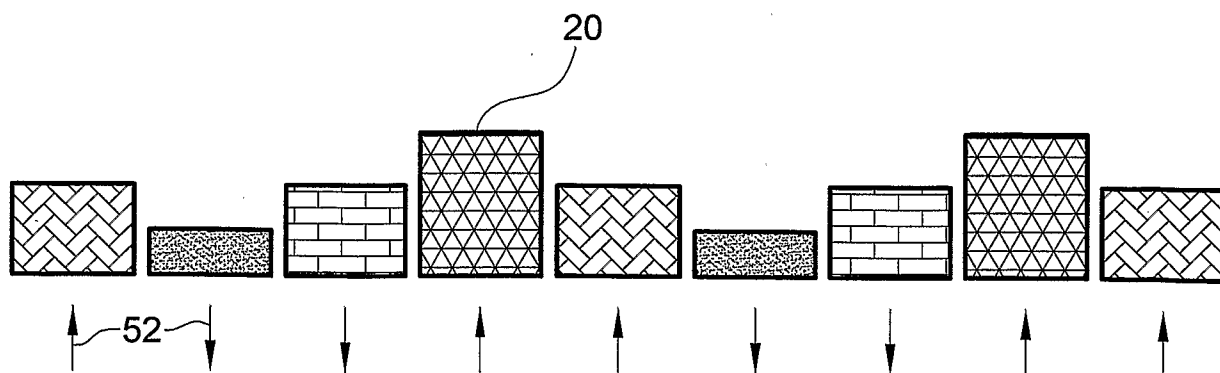


Fig. 7b

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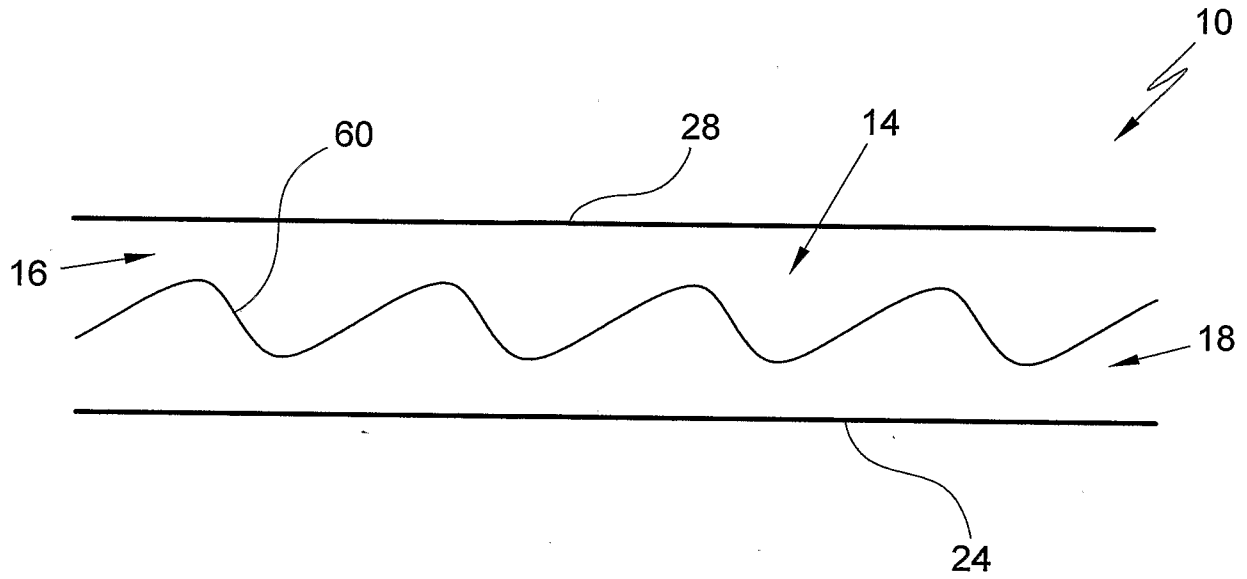


Fig.8

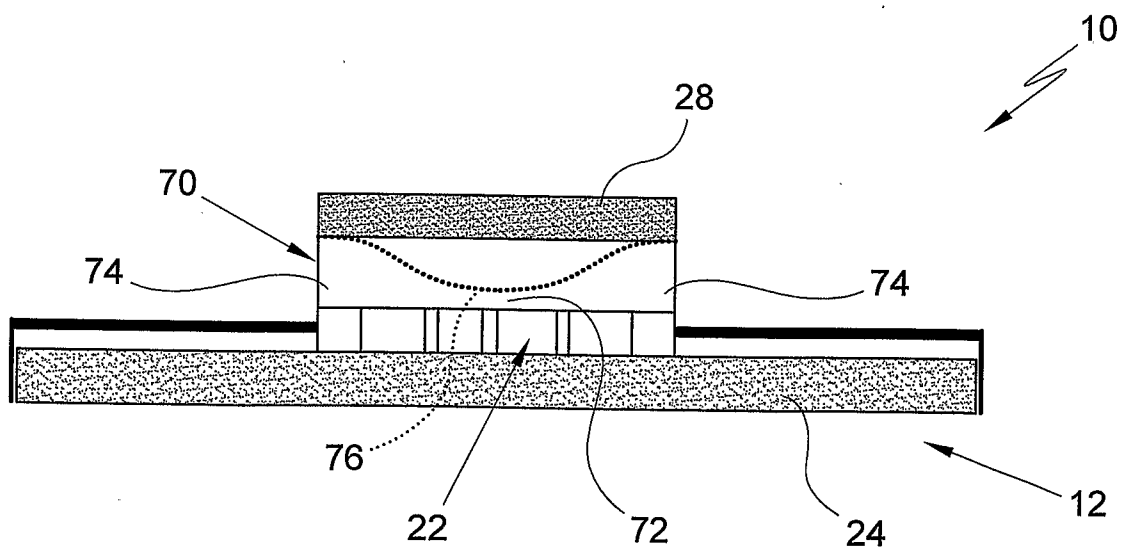


Fig.9

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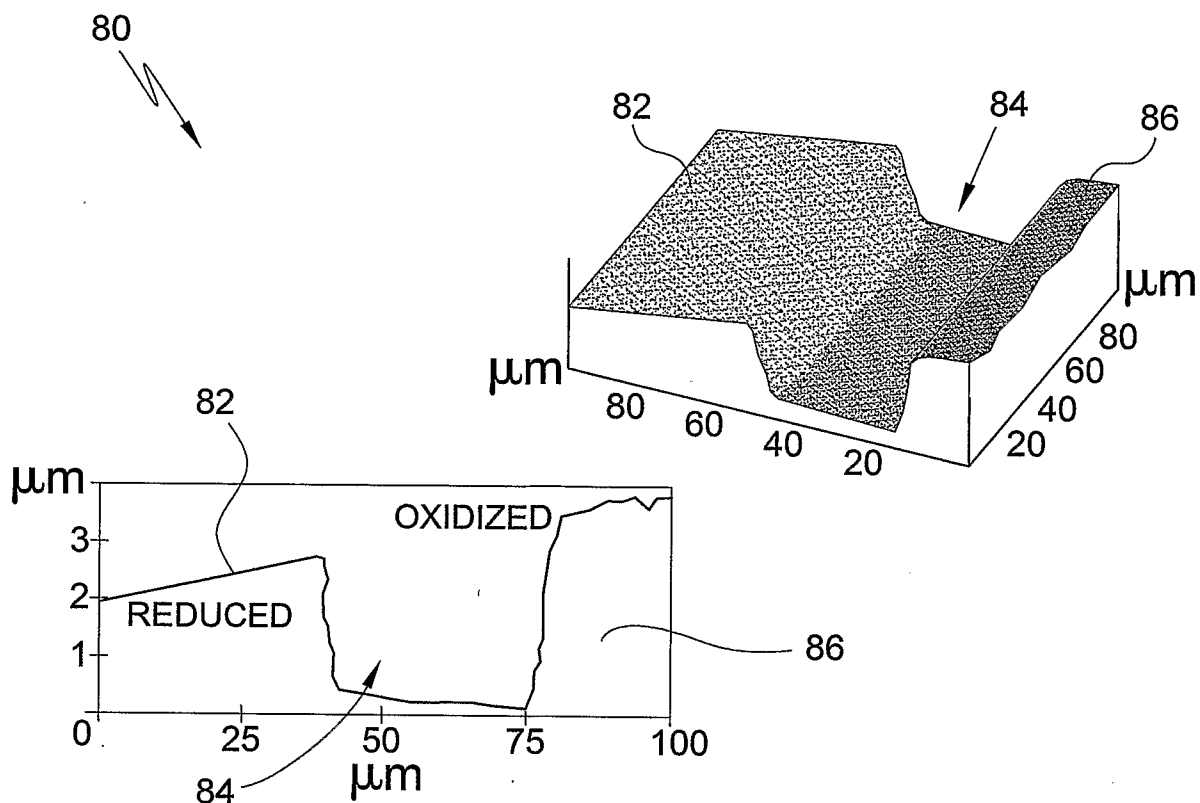


Fig.10a

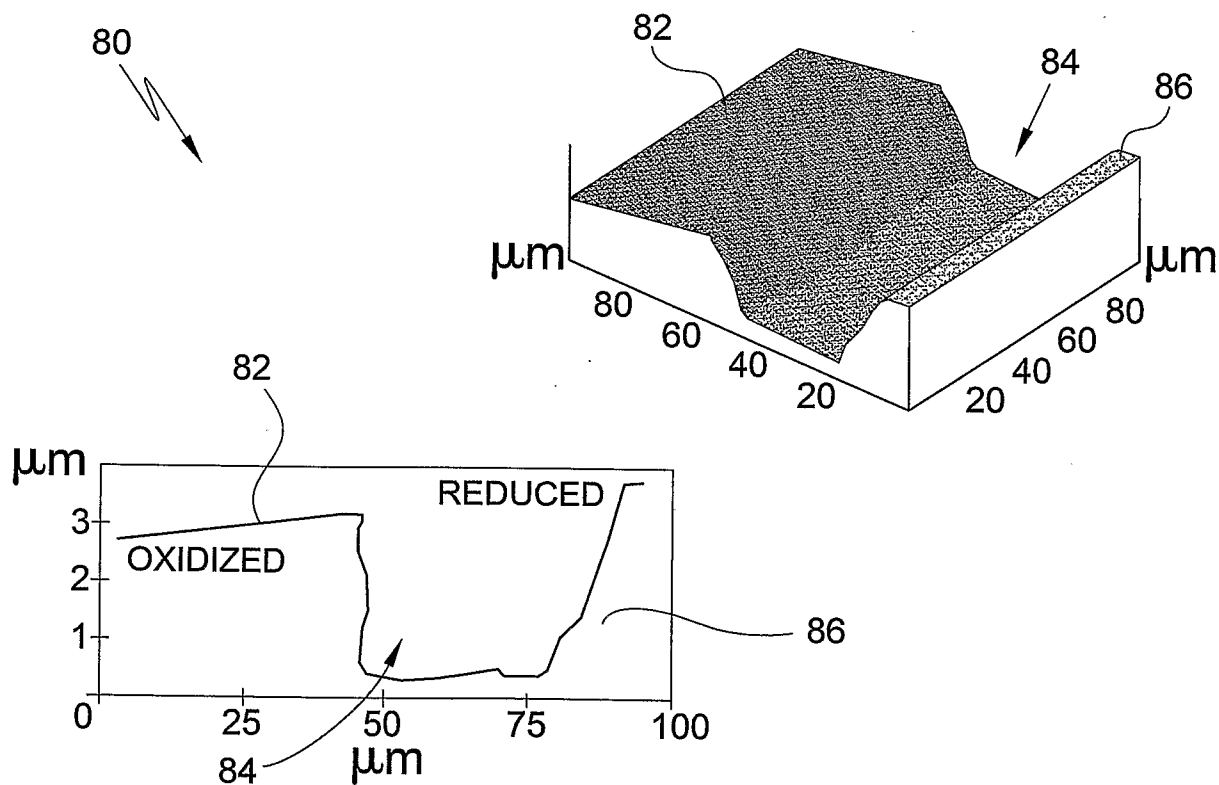


Fig.10b

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NZ2006/000199

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

B81B 3/00 (2006.01)**B81B 7/02** (2006.01)**F04B 45/00** (2006.01)**A61M 1/12** (2006.01)**F04B 43/00** (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)

DWPI: IPC: B81B 3/-, 7/- with keywords: micropump, microfabrication, microfluid, nanofabrication, nanofluid, pump, displacement, fluid, electrolyte, liquid, polymer, conduct, actuate, expand, swell, expansion, elongate, extend, peristaltic, deliver, dispense, discharge, aspirate, supply, drive, impel, move, convey, propagate, transport, drop.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002/0081218 A1 (SHARMA et al.) 27 June 2002 Figures 1-4 and description	1-4, 6, 8-10, 22
X	US 2003/0047220 A1 (LOPEZ et al.) 13 March 2003 Figure 4, paragraphs [0084] – [0103]	1-4, 7-10, 22
P,X	US 2006/0073035 A1 (SUNDARARAJAN) 6 April 2006 Figures 1-2b, 15 and description	1-3, 6-10, 22

☒ Further documents are listed in the continuation of Box C☒ See patent family annex

* "A"	Special categories of cited documents: 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 12 October 2006	Date of mailing of the international search report 24 OCT 2006
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. (02) 6285 3929	Authorized officer KURT TOBLER Telephone No : (02) 6283

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NZ2006/000199

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2004/076859 A2 (BANISTER) 10 September 2004 Figures 1-3 and description	

Information on patent family members

PCT/NZ2006/000199

Patent Document Cited in Search Report				Patent Family Member			
US	2002/0081218	EP	1219834 A1	US	6435840 B1		
US	2003/0047220 A1	US	6491061 B1	US	6615855 B2	US	6755621 B2
US	2006/0073035 A1		NONE				
WO	2004/076859 A2	CN	1774577 A	EP	1611353 A2	US	2004234401 A1

END OF ANNEX