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(54) **MICRO DEVICE INCORPORATING PROGRAMMABLE ELEMENT**

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Related U.S. Application Data

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(51) **Int. Cl.**

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C12M 1/38	(2006.01)
F01D 15/12	(2006.01)
F16D 27/00	(2006.01)

(52) **U.S. Cl.** **417/214**; 435/286.5; 435/286.7; 415/123; 192/21.5

(58) **Field of Classification Search** .... 416/169 R, 416/169 A; 415/123; 192/21.5, 58.1, 82 T, 192/58.63; 188/266; 417/214; 435/286.5, 435/286.7

See application file for complete search history.

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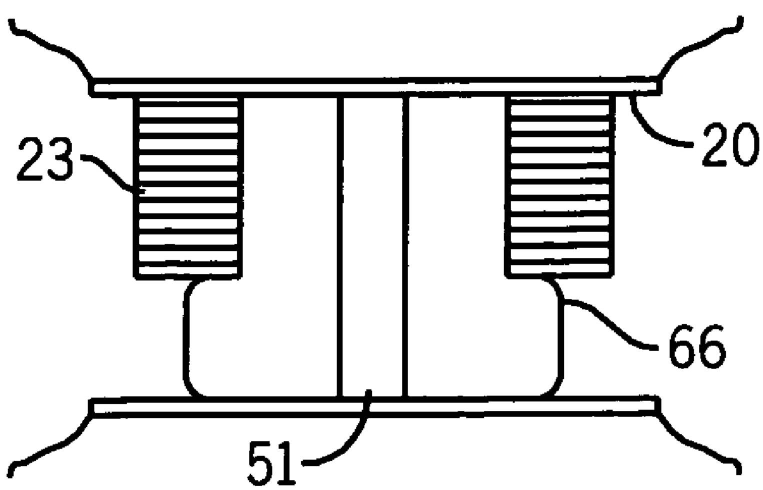
(57) **ABSTRACT**

A micro device is provided that includes a body defining a chamber for receiving fluid. A rotational element is disposed in the chamber for acting on the fluid. The rotational element is rotatable about an axis in response to a rotating magnetic field. The micro device further includes a clutch mechanism having a first disengaged configuration and a second engaged configuration wherein the clutch mechanism engages the rotational element and prevents rotation of the same.

30 Claims, 6 Drawing Sheets



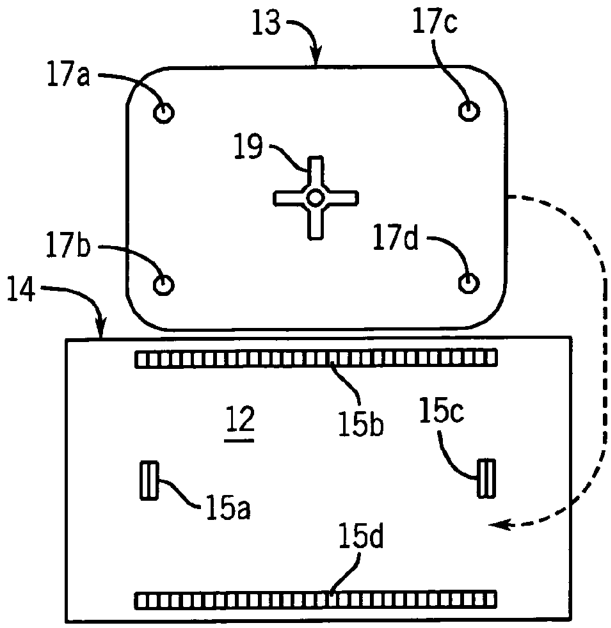
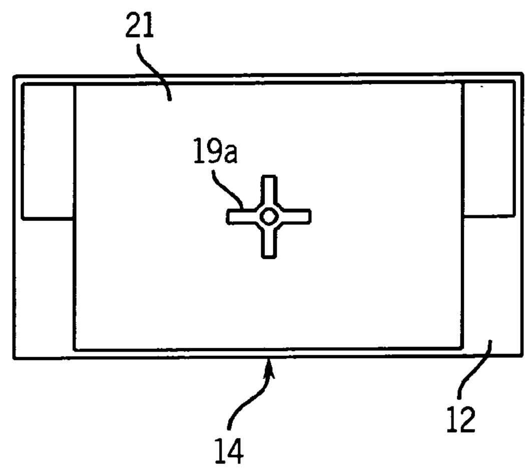


FIG. 1

FIG. 2



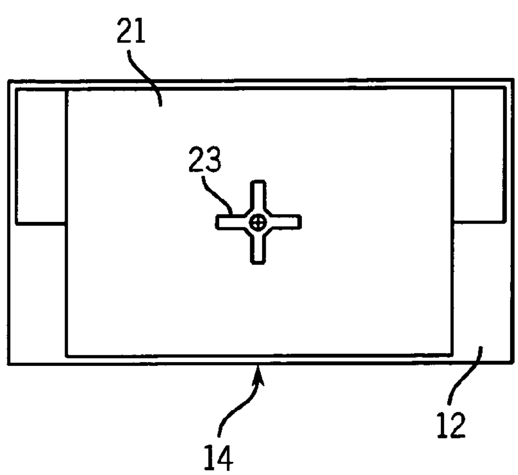


FIG. 3

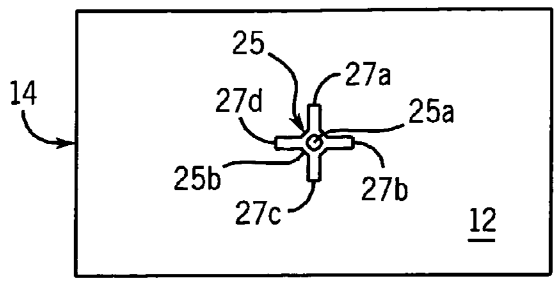


FIG. 4

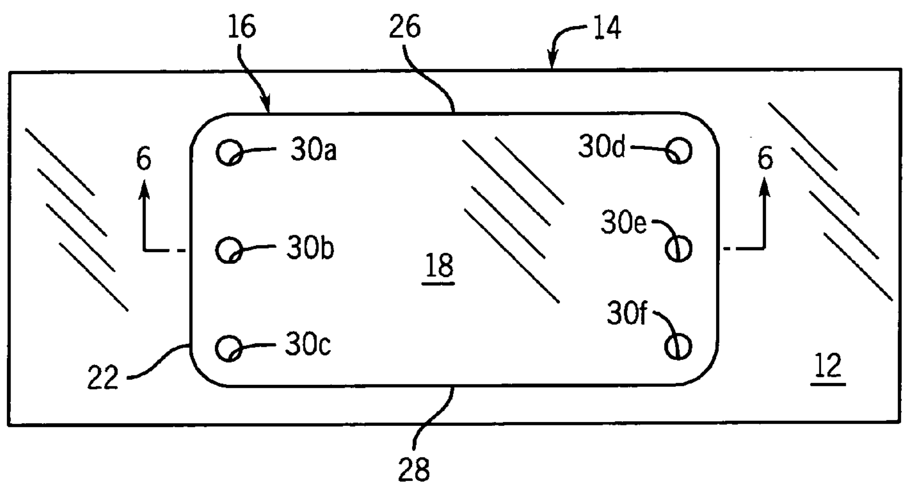


FIG. 5

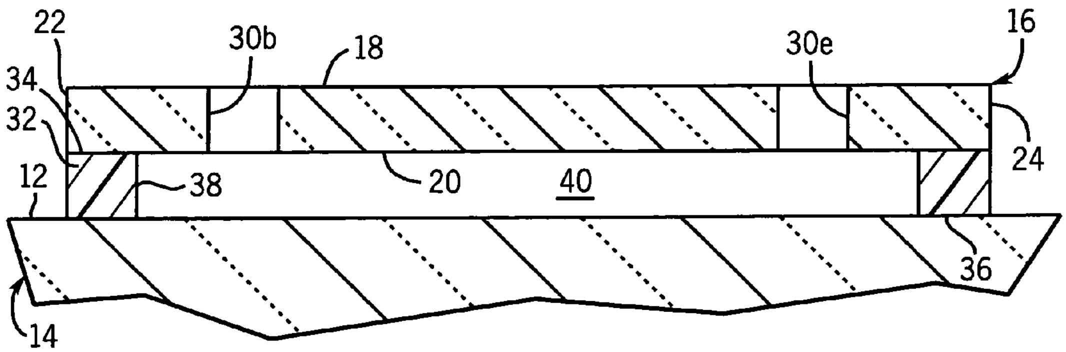


FIG. 6

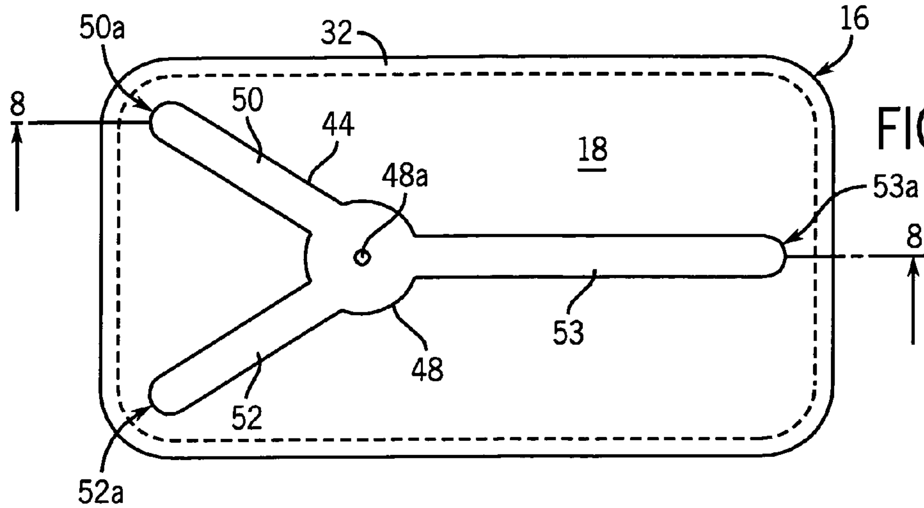
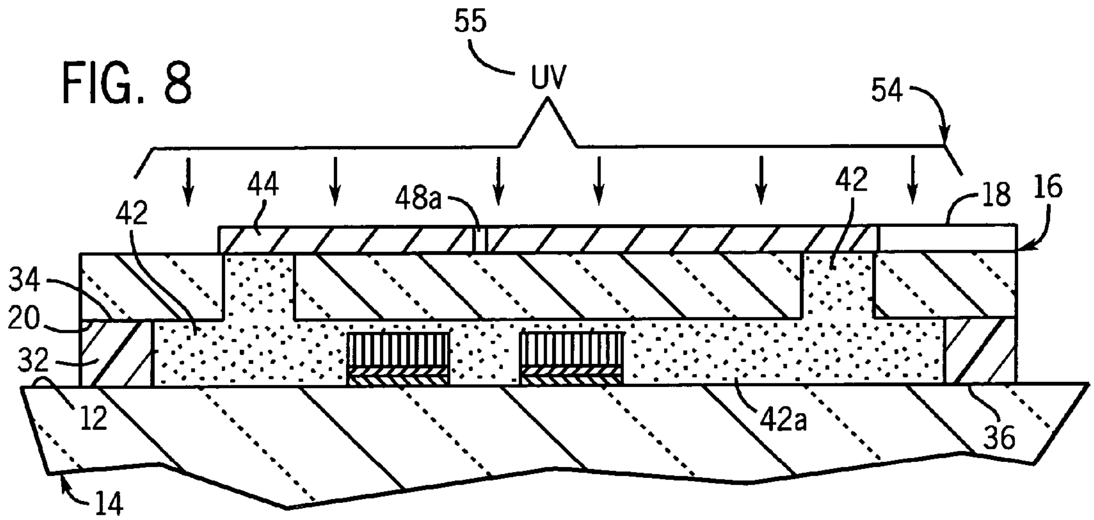


FIG. 7

FIG. 8



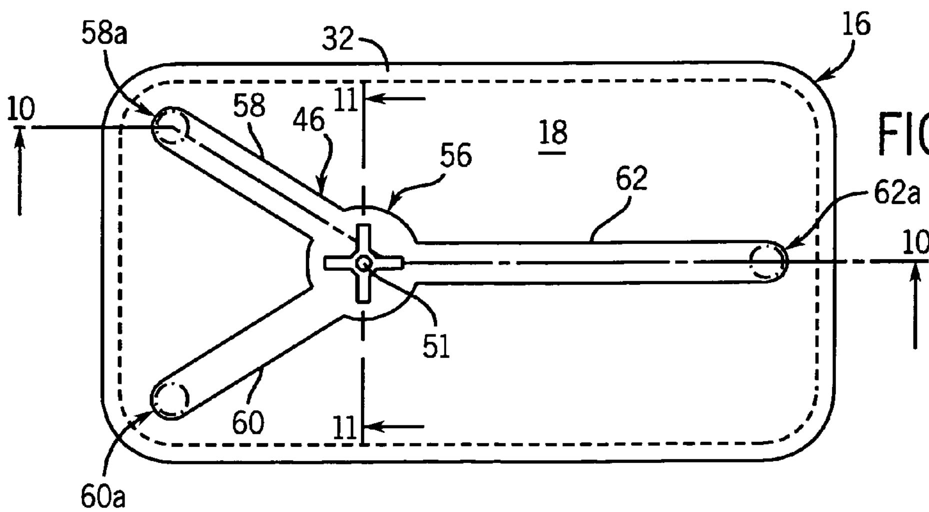


FIG. 9

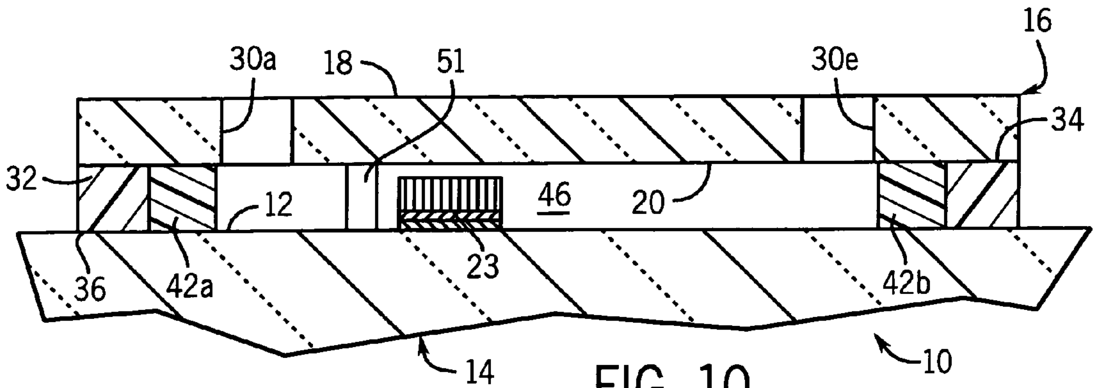
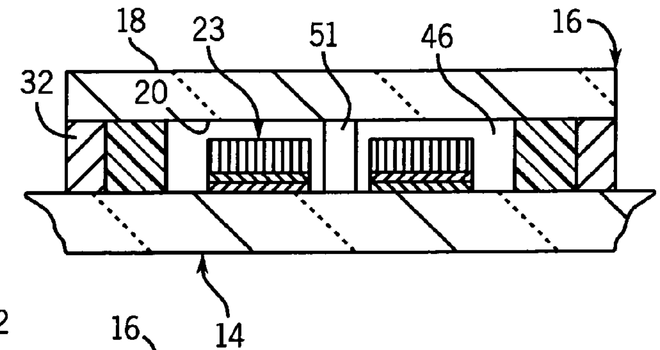


FIG. 10

FIG. 11



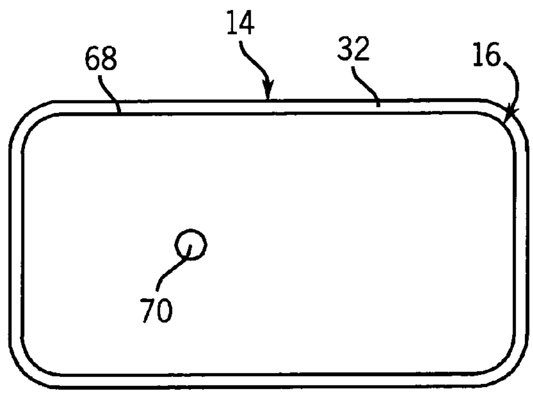
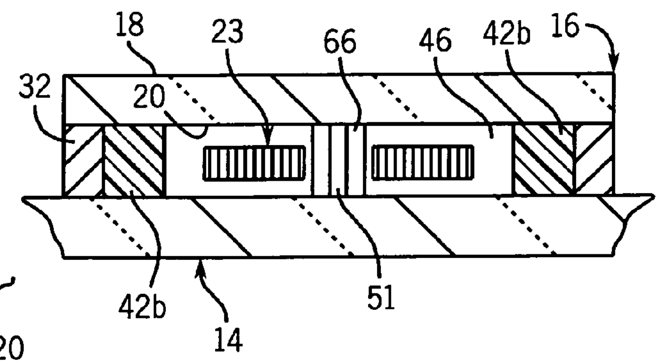


FIG. 12

FIG. 13



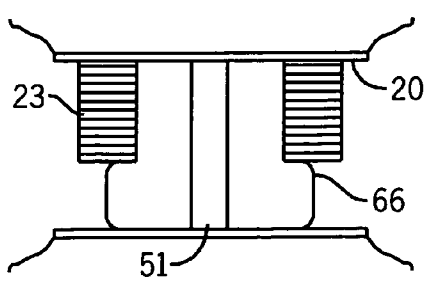


FIG. 13a

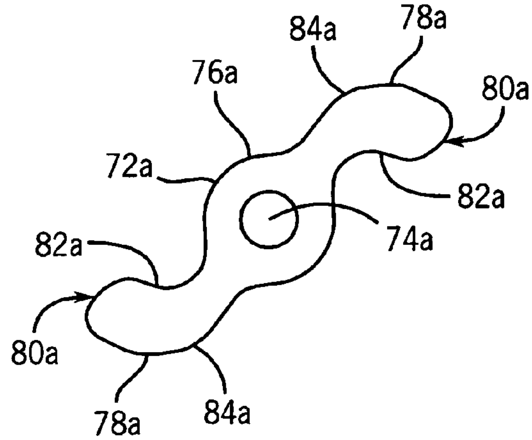


FIG. 14a

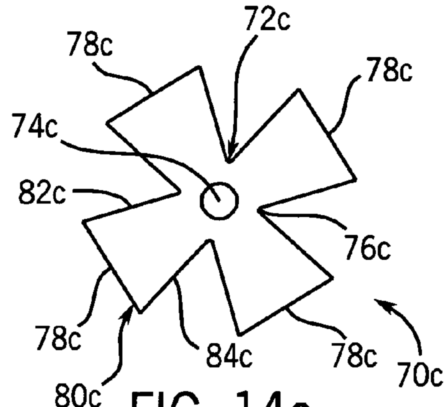


FIG. 14c

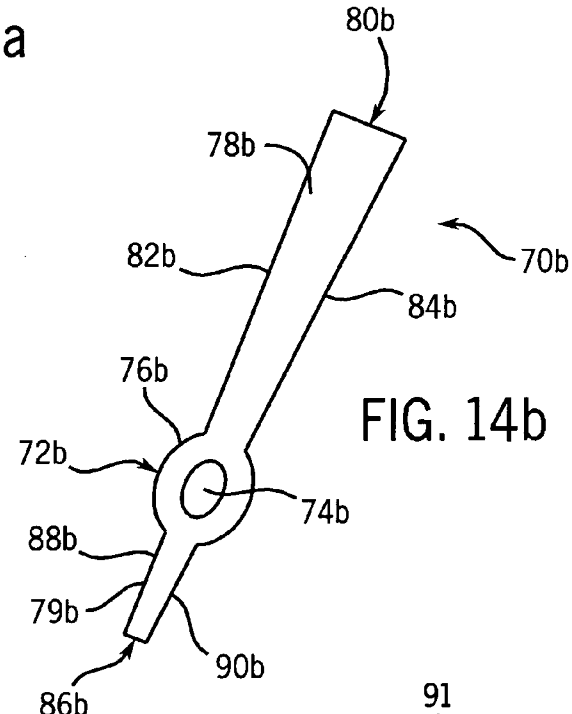


FIG. 14b

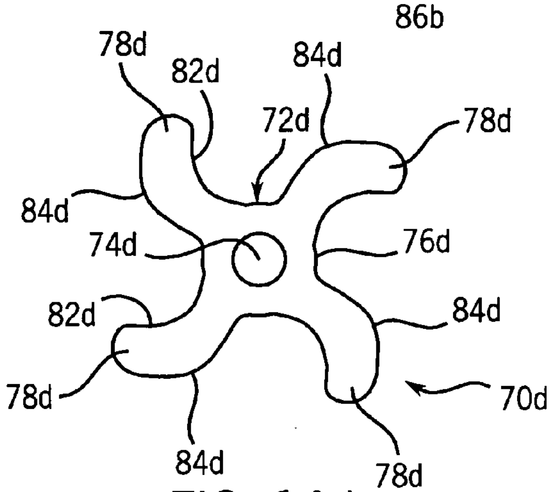


FIG. 14d

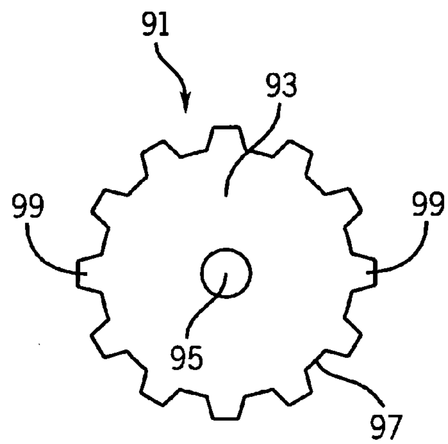


FIG. 14e

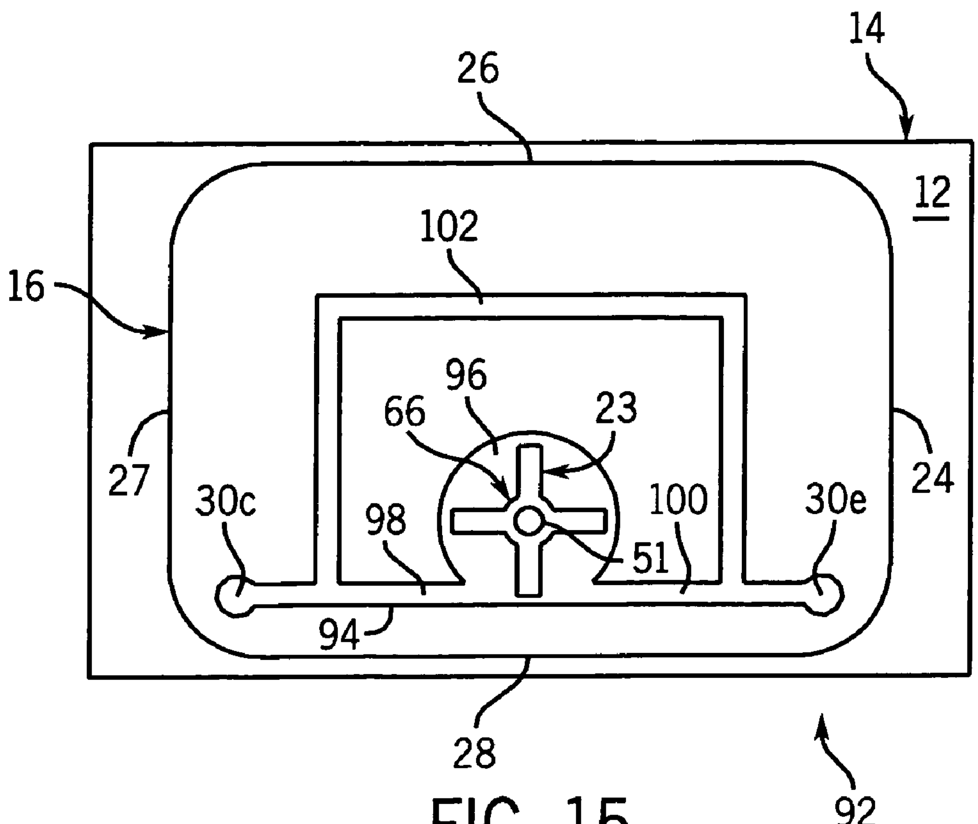


FIG. 15

MICRO DEVICE INCORPORATING PROGRAMMABLE ELEMENT

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application Ser. No. 60/572,983, filed May 20, 2004.

REFERENCE TO GOVERNMENT GRANT

This invention was made with United States government support awarded by the following agencies: DOD ARPA F30602-00-2-0570. The United States has certain rights in this invention.

FIELD OF THE INVENTION

This invention relates generally to microsystems, and in particular, to a micro device incorporating a programmable rotational element for acting on a fluid flowing therepast.

BACKGROUND AND SUMMARY OF THE INVENTION

As is known, Microsystems have emerged as a useful tool in such areas as electronics, research and clinical medicine. Microsystems are considered to be any device or unit made up of a number of microengineered and/or micromachined components, such as miniature pumps and valves. In an attempt to develop Microsystems that perform more complex functions, ongoing research is being conducted in the area of microelectromechanical systems (MEMS). Due to various innovations in the integrated circuit industry (e.g., micromachining), the development of microsystems has progressed rapidly. For example, various microsystems which incorporate microengineered and/or micromachined components such as sensors, actuators, valves and the like are now widely used in academia. These microsystems are designed for various applications, including microfluidics and drug delivery.

Further expansion of the uses for microsystems has been limited due to the difficulty and expense of fabrication. While silicon-based Microsystems have proven well suited to optical and physical sensing applications, the use of silicon-based devices in other applications is not straightforward. Silicon-based approaches typically rely on actuation methods (electrostatic, thermal, electromagnetic) that are not suitable for direct interface with liquid and organic systems. In addition, the integration of microscale valves and other microscale components into micro devices has proven problematic. Often, the manufacturing process that provides a useful microscale valve is vastly different from the manufacturing process that provides a useful microscale pump or sensor. Hence, different device components necessarily require different materials for construction and different types of manufacturing steps. As a result, the integrating of several microengineered components into a single micro device is both time consuming and expensive.

In order to overcome the limitations of prior MEMS technology, polymer-based fabrication techniques have been developed. During polymer-based fabrication, liquid-phase photopolymerization is utilized to allow for the rapid creation of microcomponents. As a result, photosensitive polymers can be patterned within a micro device without the additional necessity of a clean-room environment. Further, liquid-phase photopolymerization is a low-temperature process (<100 degrees Celsius) and allows the fabricator to construct a desired microcomponent at a designated area on a substrate.

Hence, it is highly desirable to provide a method of fabricating a micro device that leverages the advantages of both silicon-based Microsystems with polymer-based fabrication techniques.

Therefore, it is a primary object and feature of the present invention to provide a micro device that incorporates a programmable element that functions without on-chip wiring or electricity.

It is a further object and feature of the present invention to provide a micro device that is simple and inexpensive to manufacture.

It is a still further object and feature of the present invention to provide a micro device that may be customized to a particular application without undue additional expense.

In accordance with the present invention, a micro device is provided that includes a body defining a chamber. The chamber has an input and an output for accommodating the flow of fluid therebetween. The micro device includes a moveable element disposed in the chamber and a clutch mechanism engageable with the moveable element for controlling the movement thereof.

The clutch mechanism has a first configuration wherein the moveable element is fixed in position and a second configuration wherein the moveable element is free move along a path. The clutch mechanism includes a polymeric material having a volume responsive to the value of an environmental property such as the pH or temperature of the fluid. The material has a first volume in response to the environmental property having a first value and a second volume in response to the property having a second value.

The moveable element includes a central hub that may have a blade extending radially therefrom and an opening therein for receiving the polymeric material. The opening is defined by an inner hub surface that is engaged by the polymeric material when the polymeric material has the second volume. As a result, the polymeric material prevents movement of the moveable element.

In a first embodiment, the blade has a terminal end radially spaced from and interconnected to the central hub by a generally arcuate edge. Alternatively, the blade may include first and second edges extending radially from the central hub and diverging from each other. It is contemplated for an alternate embodiment of the moveable element to include a radially outer edge having a plurality of teeth circumferentially spaced thereabout.

In accordance with a further aspect of the present invention, a micro device is provided that includes a body defining a chamber. The chamber has an input and an output for accommodating the flow of fluid therebetween. A rotational element is disposed in the chamber. The rotation element includes a central hub and is rotatable about an axis. A clutch mechanism is engageable with the rotational element in response to an environmental property. The clutch mechanism controls rotation of the rotational element.

The central hub of the rotational element has an opening therethrough for receiving a post disposed in the chamber. The clutch mechanism includes a polymeric material that extends about the post and that has a volume responsive to the value of the environmental property, such as the pH or temperature of the fluid. The polymeric material has a first volume in response to the property having a first value and a second volume in response to the property having a second value. The opening through the central hub of the rotational element is defined by an inner hub surface. In its second volume, the polymeric material engages the inner hub surface and prevents rotation of the rotational element.

In a first embodiment, the blade has a terminal end radially spaced from and interconnected to the central hub by a generally arcuate edge. Alternatively, the blade may include first and second edges extending radially from the central hub and diverging from each other. An alternate embodiment of the rotational element includes a radially outer edge having a plurality of teeth circumferentially spaced thereabout.

In accordance with a still further aspect of the present invention, a micro device is provided. The micro device includes a body defining a chamber for receiving fluid. A moveable element is disposed in the chamber and is moveable along a predetermined path in response to an external stimulus. The micro device further includes a clutch mechanism having a first disengaged configuration and a second engaged configuration wherein the clutch mechanism engages the moveable element.

The clutch mechanism is movable between the disengaged configuration and the engaged configuration in response to an environmental property, such as the pH or temperature of the fluid. The moveable element includes a central hub having an opening therethrough for receiving a post disposed in the chamber. The clutch mechanism includes polymeric material extending about the post. The polymeric material has a volume responsive to the value of the environmental property. The polymeric material is spaced from the moveable element with the clutch mechanism in the first disengaged configuration and the polymeric material engages the moveable element with the clutch mechanism in the second engaged configuration.

The body defines a first input channel having an output communicating with the chamber and an output channel having an input communicating with the chamber. In a first embodiment, the body may define a second input channel having an output communicating with the chamber. Alternatively, the body may define a feedback channel having an input communicating with the output channel downstream of the chamber and an output communicating with the input channel upstream of the chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings furnished herewith illustrate a preferred methodology of the present invention in which the above advantages and features are clearly disclosed as well as others which will be readily understood from the following description of the illustrated embodiment.

In the drawings:

FIG. **1** is a schematic view of a first step in fabricating a micro device in accordance with the present invention;

FIG. **2** is a schematic view of a second step in fabricating the micro device of the present invention;

FIG. **3** is a schematic view of a third step in fabricating the micro device of the present invention;

FIG. **4** is a top plan view of the micro device of the present invention during the fabrication process;

FIG. **5** is a schematic, top plan view of a fourth step in fabricating the micro device of the present invention;

FIG. **6** is a cross-sectional view of the micro device of the present invention taken along line **6-6** of FIG. **5**;

FIG. **7** is a top plan view of the micro device of FIG. **5** having an optical mask affixed to the upper surface thereof;

FIG. **8** is a cross-sectional view of the micro device of the present invention taken along line **8-8** of FIG. **7** showing a fifth step in the method of the present invention wherein a cavity within the micro device has polymerizable material injected therein;

FIG. **9** is a top plan view of the micro device of the present invention during the fabrication process;

FIG. **10** is a cross-sectional view of the micro device of the present invention taken along line **10-10** of FIG. **9**;

FIG. **11** is a cross-sectional view of the micro device of the present invention taken along line **11-11** of FIG. **9**;

FIG. **12** is a top plan view of the micro device of FIG. **9** having a second optical mask affixed to the upper surface thereof;

FIG. **13** is a cross-sectional view, similar to FIG. **11**, of the completed micro device of the present invention;

FIG. **13***a* is a cross-sectional view of the completed micro device of the present invention with the hydrogel clutch mechanism thereof in an expanded configuration;

FIG. **14***a* is a top plan view of a first embodiment of a rotational element for the micro device of the present invention;

FIG. **14***b* is a top plan view of a second embodiment of a rotational element for the micro device of the present invention;

FIG. **14***c* is a top plan view of a third embodiment of a rotational element for the micro device of the present invention;

FIG. **14***d* is a top plan view of a fourth embodiment of a rotational element for the micro device of the present invention;

FIG. **14***e* is a top plan view of a fifth embodiment of a rotational element for the micro device of the present invention; and

FIG. **15** is a schematic, top plan view of an alternate embodiment of a micro device in accordance with the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIGS. **13** and **15**, a micro device fabricated in accordance with a methodology as hereinafter described is generally designated by the reference numeral **10**. Referring to FIG. **1**, in order to fabricate micro device **10**, optical mask **13** is positioned on upper surface **12** of microscope slide **14**. It is contemplated for slide **14** to be formed from glass, however, other substrates, such as a silicon wafer or print circuited board may be used without deviating from the scope of the present invention. Upper surface **12** of slide **14** is coated with a bottom layer of titanium (Ti) of approximately 0.05 micrometers, an intermediate layer of copper (Cu) of approximately 0.35 micrometers, and a top layer of Ti of 0.05 micrometers. The bottom layer of Ti serves to promote adhesion of the coating to slide **14**. The top layer of Ti prevents oxidation of the intermediate layer of Cu.

Optical mask **13** is spaced from upper surface **12** of slide **14** by a plurality of pieces **15***a*-**15***d* of double sided adhesive tape so as to define a cavity therebetween. Mask **13** includes a plurality of fill holes **17***a*-**17***d* to allow the cavity to be filled with a polymerizable material, e.g. a pre-polymer mixture of poly-isobornylacrylate, tetraethylene glycol dimethacrylate, and 2,2-dimethoxy-2-phenylacetophenone, and pattern **19** thereon corresponding to the desired shape to be transferred to the polymerizable material, as hereinafter described. Ultraviolet light generated by UV source **55**, FIG. **8**, is directed towards optical mask **13** at an angle generally perpendicular thereto. As is known, the polymerizable material within the cavity between optical mask **13** and upper surface **12** of slide **14** polymerizes and solidifies when exposed to ultraviolet light **54**. It can be appreciated that pattern **19** of optical mask **13** shields a portion of the polymerizable material from the ultraviolet light such that the portion not exposed to the ultraviolet light does not polymerize and remains in a fluidic state.

Referring to FIGS. **2-3**, optical mask **13** is removed and the fluidic portion of the polymerizable material is flushed from cavity **19***a* in polymerized material **21** utilizing ethanol. Thereafter, the portion of the top layer of Ti communicating with cavity **19***a* is removed by placing slide **14** in a bath of HF:H_2O=1:10, thereby exposing the underlying intermediate layer of Cu. The exposed portion of the intermediate layer of Cu is rinsed with water and placed in a nickel sulfamate bath. Nickel (Ni) is electroplated onto the exposed portion of the intermediate layer of Cu to form rotational element **23**. Polymerized material **21** is removed from slide **14** by soaking slide **14** in methanol for several hours. In addition, the portions of the Ti/Cu/Ti layers on upper surface **12** of slide **14** outside of rotational element **23** are selectively removed utilizing HAC:H_2O_2:H_2O=1:1:10. As best seen in FIG. **4**, rotational element **23** includes central hub **25** having an inner surface **25***a* defining a central aperture therethrough and a radially outer surface **25***b*. A plurality of circumferentially spaced mixing blades **27***a*-**27***d* extending from outer surface **25***b* of central hub **25**, for reasons hereinafter described.

Referring to FIGS. **5-6**, cartridge **16** is formed from a polycarbonate material and includes upper and lower surfaces **18** and **20**, respectively, interconnected by first and second ends **22** and **24**, respectively, and first and second sides **26** and **28**, respectively. A plurality of fill holes **30***a*-**30***f* extend through cartridge **16** and communicate with upper and lower surfaces **18** and **20**, respectively, thereof.

Gasket **32** includes an upper surface **34** affixed to lower surface **20** of cartridge **16** adjacent the outer periphery thereof. Lower surface **36** of gasket **32** is affixed to upper surface **12** of microscope slide **14**. As assembled, inner surface **38** of gasket **32**, lower surface **20** of first layer **16** and upper surface **12** of microscope slide **14** define a cavity **40** for receiving polymerizable material **42** therein, FIG. **8**. The material is injected into cavity **40** through any one of the openings **30***a*-**30***f* through the cartridge **16**.

Referring to FIG.**7**, optical mask **44** is affixed to upper surface **18** of first layer **16**. It is intended that optical mask **44** correspond to the shape of a channel network **46** to be formed in cavity **40**, FIG. **9**, as hereinafter described. By way of example, optical mask **44** is generally Y-shaped and includes a generally circular central portion **48** having aperture **48***a* extending therethrough that overlaps a portion of the aperture though central hub **25** of rotational element **23**. First and second legs **50** and **52**, respectively, diverge from central portion **48** and terminate at ends **50***a* and **52***a* that overlap openings **30***a* and **30***c*, respectively, through cartridge **16**. In addition, optical mask **44** includes third leg **53** extending therefrom and terminating at end **53***a* overlapping opening **30***e* of cartridge **16**.

As best seen in FIG. **8**, ultraviolet light generally designated by the reference numbers **54** is generated by UV source **55**, and is directed towards micro device **10** at an angle generally perpendicular to upper surface **18** of cartridge **16**. As is known, the polymerizable material **42** polymerizes and solidifies when exposed to ultraviolet light **54**. It can be appreciated that optical mask **44** shields a first portion **42***a* of the polymerizable material **42** from ultraviolet light **54**. As a result, second portion **42***b* of material **42**, which is exposed to ultraviolet light **54**, polymerizes and solidifies. On the other hand, first portion **42***a* of material **42**, which is not exposed to ultraviolet light **54**, does not polymerize and remains in a fluidic state.

Referring to FIGS. **9-11**, after polymerization of second portion **42***b* of material **42** by ultraviolet light **54**, optical mask **44** is removed from upper surface **18** of cartridge **16**. In addition, the non-polymerized portion **42***a* of the material is flushed from channel network **46** and openings **30***a*, **30***c* and **30***e* in first layer **16** using ethanol. It can be appreciated that channel network **46** has a generally Y-shape that corresponds to the shape of optical mask **44** and includes post **51** projecting vertically from upper surface **12** of slide **14** into channel network **46** through the aperture in central hub **25** of rotational element **23**. Channel network **46** includes central chamber **56** housing rotational element **23**. First and second legs **58** and **60**, respectively, extending from central chamber **56** and diverge from each other. Terminal end **58***a* of leg **58** of channel network **46** communicates with opening **30***a* through cartridge **16**. Terminal end **60***a* of second leg **60** of channel network **46** communicates with opening **30***c* through cartridge. Channel network **46** further includes third leg **62** extending from central chamber **56** and terminating at terminal end **62***a* that communicates with opening **30***e* through cartridge **16**.

After formation of channel network **46**, hydrogel **66** is injected into channel network **46** through any one of the openings **30***a*, **30***c* or **30***d* through the cartridge **16** and optical mask **68** is affixed to upper surface **18** of first layer **16**, FIG. **12**. It is intended that optical mask **68** include opening **70** therethrough corresponding to a desired pattern for the hydrogel **66** about post **51**, for reasons hereinafter described. Ultraviolet light is directed towards micro device **10** at an angle generally perpendicular to upper surface **18** of cartridge **16** such that a gel matrix is formed about post **51** that changes its volume configuration depending on its surrounding environment. For example, hydrogel **66** may expand and contract in response to stimuli such as changes in temperature, light, electric fields or pH levels of the environment within central chamber **56** of channel network **46**. However, it can be appreciated that hydogel **66** may be responsive to other environmental parameters without deviating from the scope of the present invention. Thereafter, rotational element **23** is released from upper surface **12** of slide **14** by flowing Ti and/or Cu etching solutions into central chamber **56** so as to remove the portions of the Ti and Cu layers from between slide **14** and rotational element **23**, FIG. **13**.

In operation, it is contemplated to expose micro device **10** to an external stimulus such as an electric field or a rotating magnetic field so as to cause rotational element **23** to rotate in a user desired direction about post **51**. First and second fluids may be introduced into channel network **46** at openings **30***a* and **30***c* in cartridge **16** so as to flow towards central chamber **56**. As the first and second fluids flow into central chamber **56**, mixing blades **27***a*-**27***d* engage the first and second fluids causing such fluids to mix. Thereafter, due to the flow rates and pressures of the first and second fluids, the mixed fluid is urged into third leg **62** in channel network **46** toward opening **30***e* in cartridge **16**. In response to a change in a predetermined environmental parameter, the volume of hydrogel **66** may increase to such point that hydrogel **66** engages inner surface **25***a* of central hub **25** of rotational element **23** thereby slowing the rate of rotation of rotational element **23** about post **51**. It can be appreciated that if the predetermined environmental parameter reaches a predetermined level or value, hydrogel **66** will expand to such a volume as to prevent the further rotation of rotational element **23** despite the presence of the rotating magnetic field. It is contemplated for hydrogel **66** to expand to such a volume as to overlap portions of the upper and lower surfaces of rotational element **23**. Once the level of the predetermined environmental parameter drops below the predetermined level, the volume of hydrogel **66** will shrink thereby allowing rotational element **23** to, once again, rotate about post **51**.

Alternatively, in response to the predetermined environmental parameter reaching a predetermined level or value, hydrogel **66** may expand into a mushroom cap shaped configuration, FIG. **13***a*. In the mushroom cap shaped configuration, hydrogel **66** exerts both a lateral force against inner surface **25***a* of central hub **25** of rotational element **23** and a downward force on the upper surface of rotational element **23** thereby causing rotational element **23** to stop rotating. Once the level of the predetermined environmental parameter drops below the predetermined level, the volume of hydrogel **66** will shrink, as heretofore described, thereby allowing rotational element **23** to, once again, rotate about post **51**.

The efficiency of the mixing process within central chamber **56** is dependant on a variety of variables, including the dimensions of mixing blades **27***a*-**27***d*, the diameter of central chamber **56**, the flow rates and pressure of the first and second fluids flowing into central chamber **56** and the diameters of first, second, and third legs **58**, **60** and **62**, respectively, of channel network **46**. As such, alternate rotational elements **70***a*-**70***d* are contemplated as being within the scope of the present invention, FIGS. **14***a*-**14***d*. Referring to FIG. **14***a*, alternate rotational element **70***a* includes central hub **72***a* having inner surface **74***a* defining a central aperture therethrough for receiving the post **51** and hydrogel **66** combination, as heretofore described, and radially outer surface **76***a*. First and second circumferentially spaced mixing blades **78***a* extend from outer surface **76***a* of central hub **72***a*. Each mixing blade **78***a* is defined by terminal end **80***a* interconnected to outer surface **76***a* by generally arcuate edges **82***a* and **84***a*.

Referring to FIG. **14***b*, alternate rotational element **70***b* includes central hub **72***b* having inner surface **74***b* defining a central aperture therethrough for receiving the post **51** and hydrogel **66** combination, as heretofore described, and radially outer surface **76***b*. First and second circumferentially spaced mixing blades **78***b* and **79***b*, respectively, extend from outer surface **76***a* of central hub **72***a*. Mixing blade **78***b* is defined by terminal end **80***b* interconnected to outer surface **76***b* by first and second diverging edges **82***b* and **84***b*, respectively. Mixing blade **79***b* is defined by terminal end **86***b* interconnected to outer surface **76***b* by first and second generally parallel edges **88***b* and **90***b*, respectively.

Referring to FIG. **14***c*, alternate rotational element **70***c* includes central hub **72***c* having inner surface **74***c* defining a central aperture therethrough for receiving the post **51** and hydrogel **66** combination, as heretofore described, and radially outer surface **76***c*. Circumferentially spaced mixing blades **78***c* extend radially from outer surface **76***c* of central hub **72***c*. Each mixing blade **78***c* is defined by terminal end **80***c* interconnected to outer surface **76***c* by first and second diverging edges **82***c* and **84***c*, respectively.

Referring to FIG. **14***d*, alternate rotational element **70***d* includes central hub **72***d* having inner surface **74***d* defining a central aperture therethrough for receiving the post **51** and hydrogel **66** combination, as heretofore described, and radially outer surface **76***d*. A plurality of circumferentially spaced mixing blades **78***d* extend from outer surface **76***d* of central hub **72***d*. Each mixing blade **78***d* is defined by terminal end **80***d* interconnected to outer surface **76***d* by generally arcuate edges **82***d* and **84***d*.

It can be appreciated that channel network **46** may be fabricated to have different configurations within micro device **10** by simply varying the configurations of optical mask **44**. In addition, it is contemplated as being within the scope of the present invention for micro device **10** to perform additional tasks beyond mixing. As such, rotational element **23** may take the form of a moveable element that moves along a linear path, arc-like path, or even an arbitrary part in response to a stimulus provided on micro device **10**. Alternatively, as best seen in FIG. **14***e*, rotational element **91** may take the form of a gear, adapted for driving a secondary gear or a device. Rotational element **91** includes central hub **93** having inner surface **95** defining a central aperture therethrough for receiving the post **51** and hydrogel **66** combination, as heretofore described, and radially outer surface **97**. A plurality of circumferentially spaced teeth **99** extends from outer surface **97** of central hub **93**. Teeth **99** of rotational element **91** are adapted to engage teeth on an adjacent gear or to drive an adjacent device in a conventional manner.

Referring to FIG. **15**, an alternate embodiment of a micro device in accordance with the present invention is generally designated by the reference numeral **92**. Micro device **92** is fabricated on slide **14** as heretofore described with respect to micro device **10** such that the polymerized portion **42***b* of polymerizable material **42** defines channel network **94** therein. Channel network **94** includes central chamber **96** having the post **51** and hydrogel **66** combination projecting vertically from upper surface **12** of slide **14** through the aperture in central hub **25** of rotational element **23**. Channel network **94** further includes input leg **98** having an input communicating with opening **30***c* in cartridge **16** and an output communicating with central chamber **96**, as well as, output leg **100** having an output communicating with opening **30***e* in cartridge **16** and an input communicating with central chamber **96**. Feedback channel **102** has an input communicating with output leg **100** and an output communicating with input leg **98**.

In operation, micro device **92** is exposed to an external stimulus such as an electric field or a rotating magnetic field so as to cause rotational element **23** to rotate in a user desired direction about the post **51** and hydrogel **66** combination. A first fluid is introduced into channel network **94** at opening **30***c* in cartridge **16** and flows toward central chamber **96** through input leg **98**. As the first fluid flows into central chamber **96**, blades **27***a*-**27***d* engage the first fluid, thereby pumping such fluid into output leg **100**. A portion of the first fluid returns to input leg **98** through feedback channel **102**. In response to a change in a predetermined environmental parameters, the volume of hydrogel **66** increase to such point that hydrogel **66** engages inner surface **25***a* of central hub **25** of rotational element **23** thereby slowing the rate of rotation of rotational element **23** about post **51** and slowing the pumping of the first fluid into output leg **100**. It can be appreciated that if the predetermined environmental parameter reaches a predetermined level, hydrogel **66** will expand to such a volume as to prevent the further rotation of rotational element **23**. As heretofore described, hydrogel **66** may expand to such a volume as to overlap to upper surface of rotational element **23** or portions of the upper and lower surfaces of rotational element **23**. Once the level of the predetermined environmental parameter drops below the predetermined level, the volume of hydrogel **66** will shrink thereby allowing rotational element **23** to, once again, rotate about post **51** and pump the first fluid into output leg **100**.

As described, the method of fabrication provided herein may be used as a stand-alone process or to append an existing procedure. Unlike conventional lithography that requires the spinning and/or casting of photosensitive materials on entire substrates, liquid-phase photopolymerization can occur at designated areas on a substrate. The process can also be appended to MEMS structures that have been previously released. Since the process described herein is liquid based, topography in not a significant concern. In addition, the ability to control component operation via local fluid parameters expands control scheme possibilities while in situ processing simplifies fabrication and eliminates the need for assembly. Further, it can be appreciated that the method of fabricating micro device **10** described herein is merely exemplary and that micro device **10** may be fabricated in other manners without deviating from the scope of the present invention.

Various modes of carrying out the invention are contemplated as being within the scope of the following claims particularly pointing out and distinctly claiming the subject matter that is regarded as the invention.

We claim:

1. A micro device including a body that defines a chamber, the chamber having an input and an output for accommodating the flow of fluid therebetween, comprising:

a moveable element disposed in the chamber, the moveable clement including an inner surface defining an opening in the moveable element; and

a clutch mechanism engageable with the moveable element for controlling the movement thereof, the clutch mechanism including an expandable polymeric material having a volume responsive to the value of a predetermined environmental property such that the material has a first volume in response to the environmental property having a first value and a second volume in response to the environmental property having a second value;

wherein:

the polymeric material extends through the opening in the element;

the polymeric material engages the inner surface of the element and prevents movement of the element with the polymeric material having the first volume; and

the polymeric material disengages from the inner surface of the element with the polymeric material having the second volume so as to allow the element to move with respect to the polymeric material.

2. The micro device of claim **1** wherein the polymeric material has a mushroom cap shape in the first volume.

3. The micro device of claim **1** wherein the moveable element includes a hub having at least one blade extending radially therefrom.

4. The micro device of claim **3** wherein the hub includes the opening therein for receiving the polymeric material.

5. The micro device of claim **3** wherein the blade has a terminal end radially spaced from and interconnected to the hub by a generally arcuate edge.

6. The micro device of claim **3** wherein the blade includes first and second edges extending radially from the hub and diverging from each other.

7. The micro device of claim **1** wherein the moveable element includes a radially outer edge having a plurality of teeth circumferentially spaced thereabout.

8. The micro device of claim **1** wherein the environmental property is pH of the fluid.

9. The micro device of claim **1** wherein the environmental property is temperature of the fluid.

10. A micro device, comprising:

a body defining a chamber, the chamber having an input and an output for accommodating the flow of fluid therebetween;

a rotational element disposed in the chamber and including a hub having an inner surface defining a central opening through the rotational member, the rotational element being rotatable about an axis; and

a clutch mechanism extending through the central opening in the hub of the rotational element and being movable between a first disengaged configuration wherein the clutch mechanism is disengaged from the inner surface of the hub of the rotational clement and a second engaged configuration wherein the clutch mechanism engages the inner surface of the hub of the rotational element in response to an environmental property of the fluid, the clutch mechanism controlling rotation of the rotational element.

11. The micro device of claim **10** wherein the micro device further comprises a post disposed in the chamber and extending through the central opening in the hub.

12. The micro device of claim **11** wherein the clutch mechanism includes polymeric material extending about the post and having a volume responsive to the value of the environmental property, the polymeric material having a first volume in response to the environmental property having a first value and a second volume in response to the environmental property having a second value.

13. The micro device of claim **12** wherein the polymeric material of the second volume engages the inner hub surface and prevents rotation of the rotational element.

14. The micro device of claim **13** wherein the rotational element includes an upper surface and wherein polymeric material of the second volume engages the upper surface of the rotational element to prevent rotation of the rotational element.

15. The micro device of claim **11** wherein the rotational clement includes a blade extending radially from the hub.

16. The micro device of claim **15** wherein the blade has a terminal end radially spaced from and interconnected to the hub by a generally arcuate edge.

17. The micro device of claim **15** wherein the blade includes first and second edges extending radially from the hub and diverging from each other.

18. The micro device of claim **15** wherein the rotational element includes a radially outer edge having a plurality of teeth circumferentially spaced thereabout.

19. The micro device of claim **11** wherein the environmental property is pH of the fluid.

20. The micro device of claim **11** wherein the environmental property is temperature of the fluid.

21. The micro device of claim **11** wherein the body includes a second input to the chamber.

22. A micro device, comprising:

a body defining a chamber for receiving fluid;

a moveable element disposed in the chamber and being moveable along a path in response to a predetermined external stimulus, the moveable element including a hub having an inner surface defining an opening through the moveable element; and

a clutch mechanism extending through the opening in the moveable element and having a first disengaged configuration wherein the clutch mechanism is disengaged from the moveable element and a second engaged configuration wherein the clutch mechanism engages the moveable element and prevents movement of the moveable element along the path, the clutch mechanism being movable between the disengaged configuration and the engaged configuration in response to an environmental property of the fluid.

23. The micro device of claim **22** wherein the environmental property is pH of the fluid.

24. The micro device of claim **22** wherein the environmental property is temperature of the fluid.

25. The micro device of claim **22** further comprising a post disposed in the chamber and extending through the opening in the hub of the moveable element.

26. The micro device of claim 25 wherein the clutch mechanism includes polymeric material extending about the post, the polymeric material having a volume responsive to the value of the environmental property.

27. The micro device of claim 26 wherein the polymeric material is spaced from the moveable element with the clutch mechanism in the first disengaged configuration and wherein the polymeric material engages the moveable element with the clutch mechanism in the second engaged configuration.

28. The micro device of claim 22 wherein the body defines a first input channel having an output communicating with the chamber and an output channel having an input communication with the chamber.

29. The micro device of claim 28 wherein the body defines a second input channel having an output communicating with the chamber.

30. The micro device of claim 28 wherein the body defines a feedback channel having an input communicating with the output channel downstream of the chamber and an output communicating with the input channel upstream of the chamber.

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