US 20090165320A1

(19) **United States**

(12) **Patent Application Publication**

DeSimone et al.

(10) **Pub. No.: US 2009/0165320 A1**

(43) **Pub. Date: Jul. 2, 2009**

(54) **PHOTOCURABLE PERFLUOROPOLYETHERS FOR USE AS NOVEL MATERIALS IN MICROFLUIDIC DEVICES**

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(21) Appl. No.: **11/825,482**

(22) Filed: **Jul. 6, 2007**

Related U.S. Application Data

(63) Continuation of application No. 10/572,764, filed on May 16, 2007, filed as application No. PCT/US04/31274 on Sep. 23, 2004.

(60) Provisional application No. 60/505,384, filed on Sep. 23, 2003, provisional application No. 60/524,788, filed on Nov. 21, 2003.

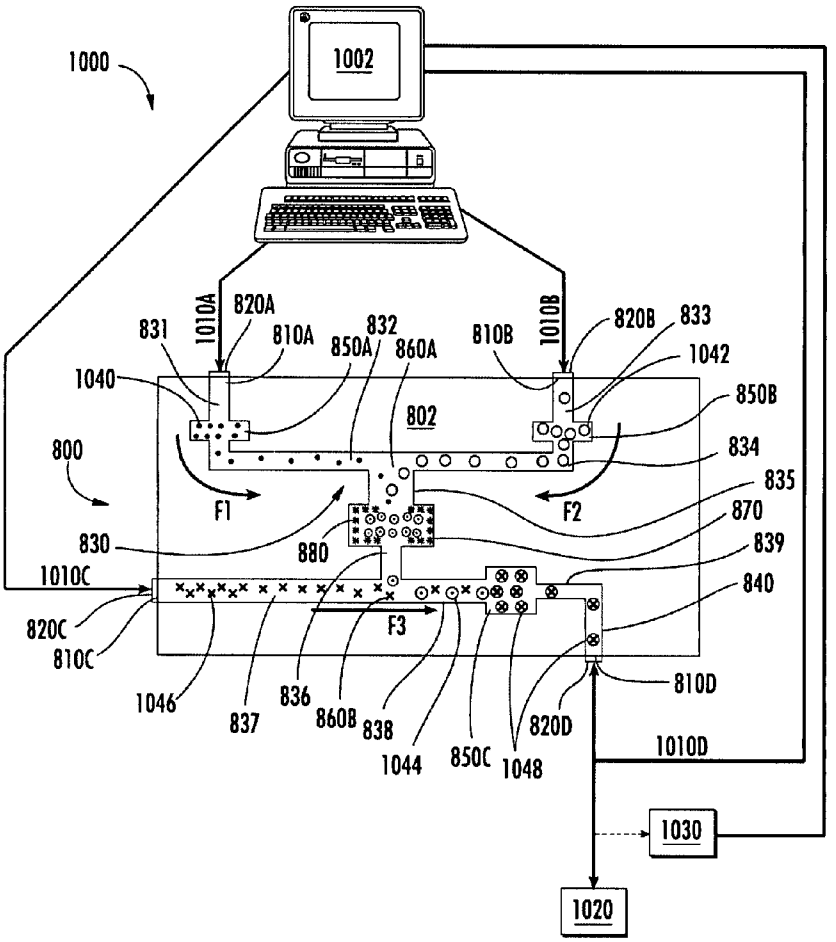
Publication Classification

(51) **Int. Cl.**
G01B 1/00 (2006.01)

(52) **U.S. Cl.** **33/700**

(57) **ABSTRACT**

A functionalized photocurable perfluoropolyether is used as a material for fabricating a solvent-resistant microfluidic device. Such solvent-resistant microfluidic devices can be used to control the flow of small amounts of a fluid, such as an organic solvent, and to perform microscale chemical reactions that are not amenable to other polymer-based microfluidic devices.



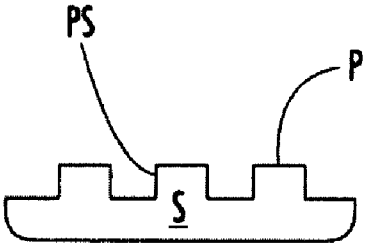


FIG. 1A

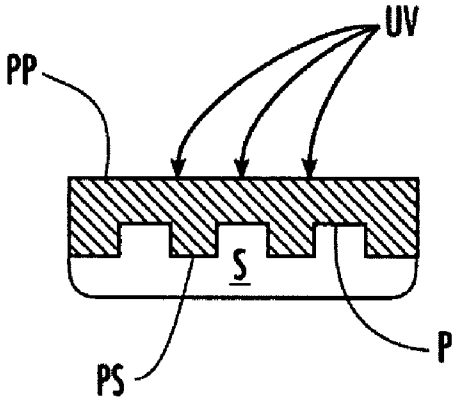


FIG. 1B

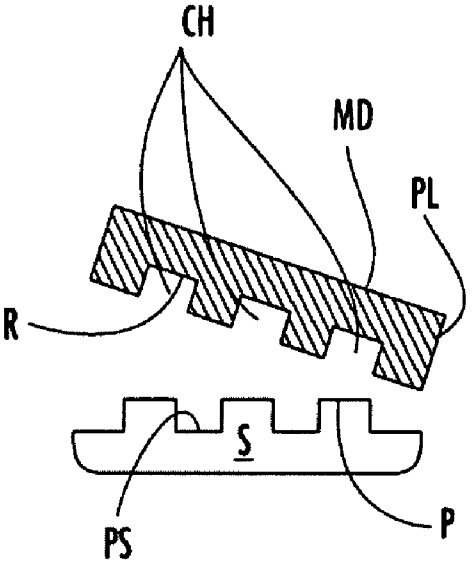


FIG. 1C

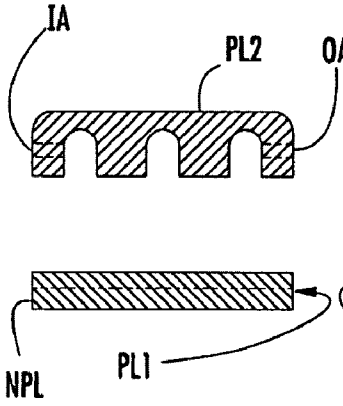


FIG. 2A

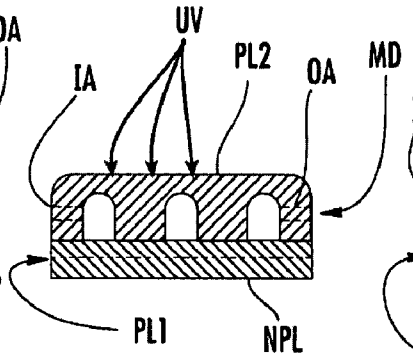


FIG. 2B

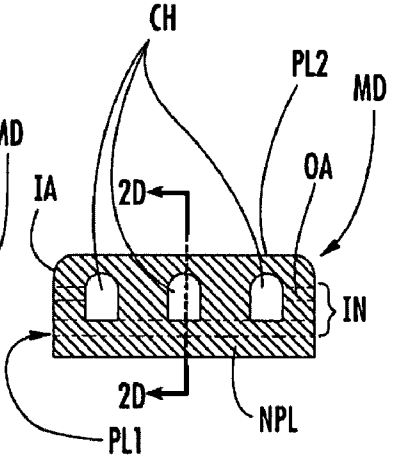


FIG. 2C

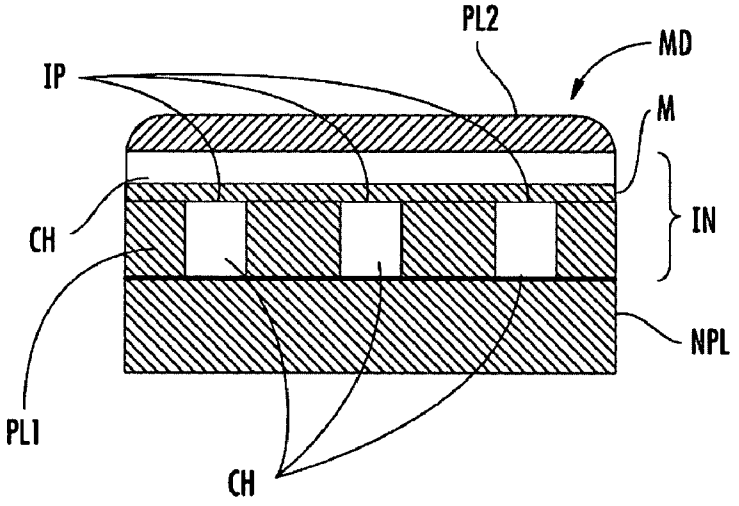


FIG. 2D

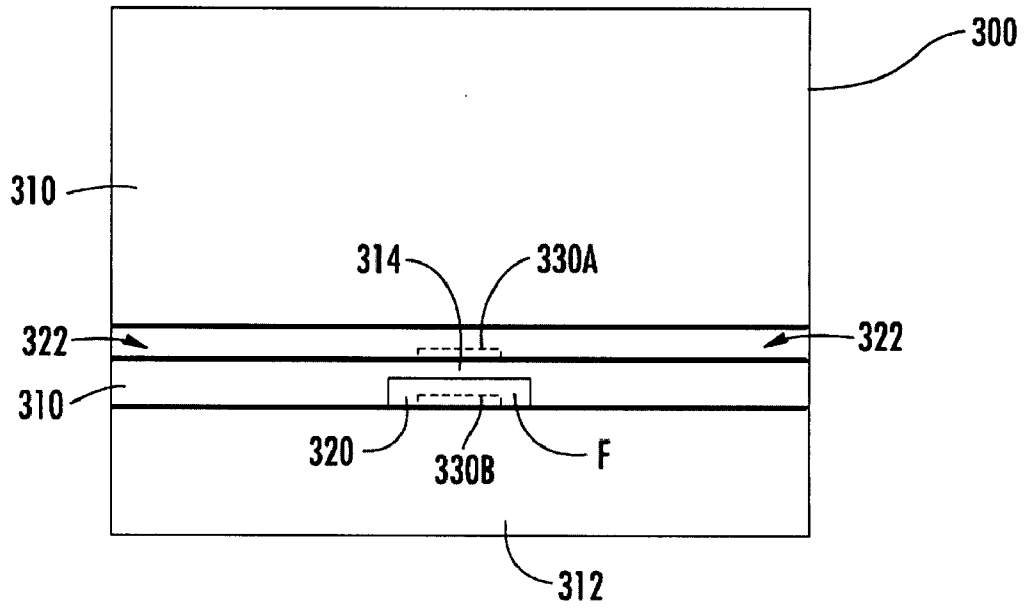

300
310
314
330A
322
322
310
320
330B
F
312

FIG. 3A

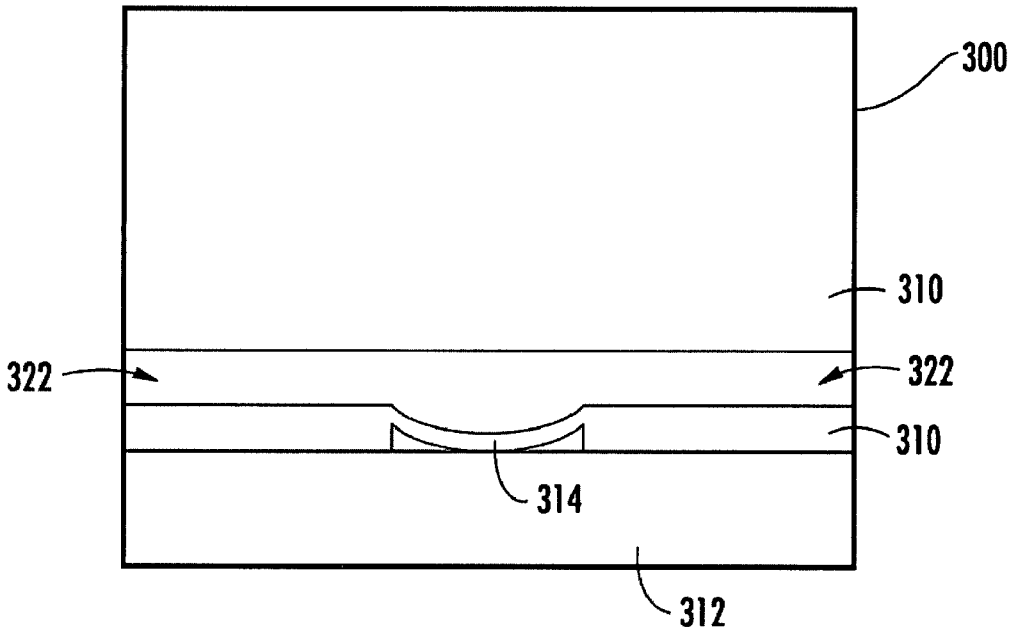

300
310
322
322
310
314
312

FIG. 3B

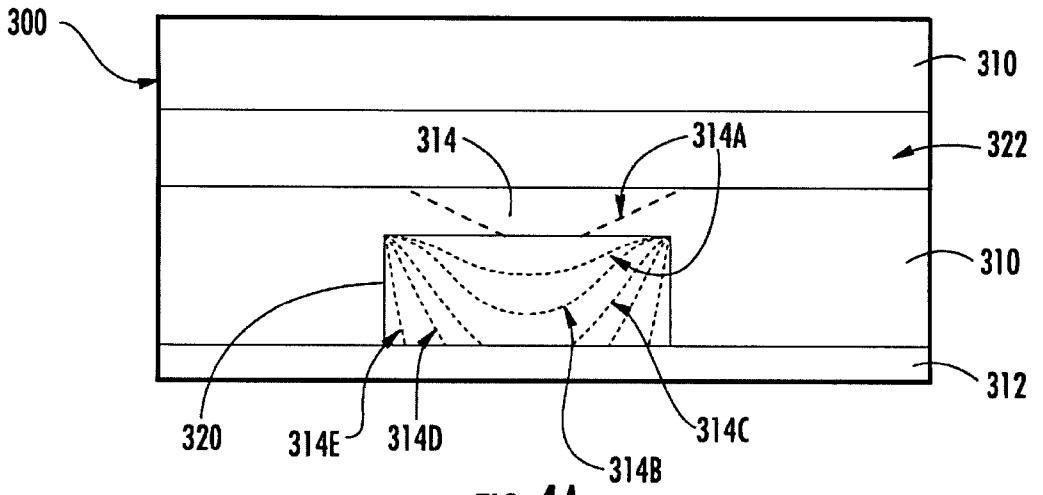

300
310
314
314A
322
310
312
320
314E
314D
314B
314C

FIG. 4A

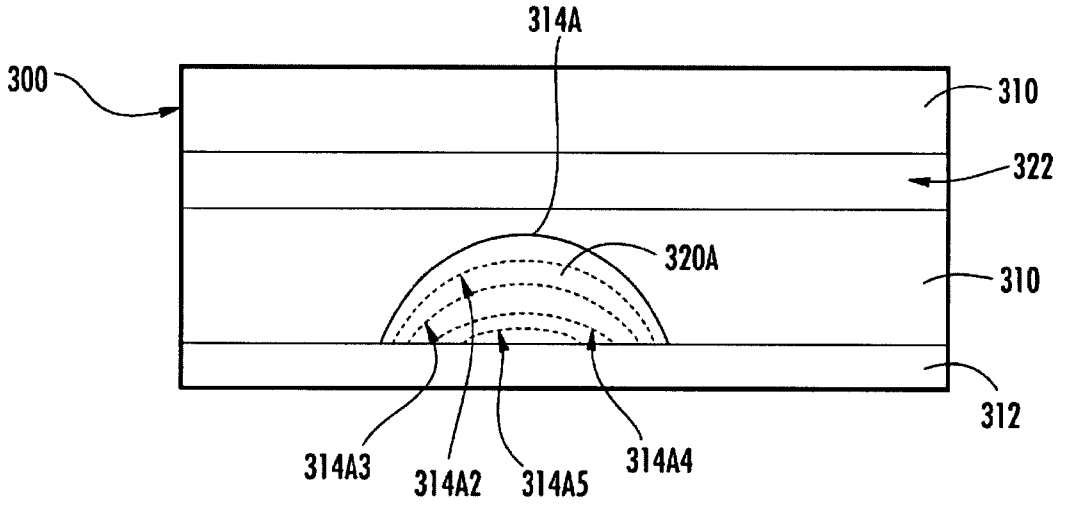

314A
300
310
322
320A
310
312
314A3
314A2
314A5
314A4

FIG. 4B

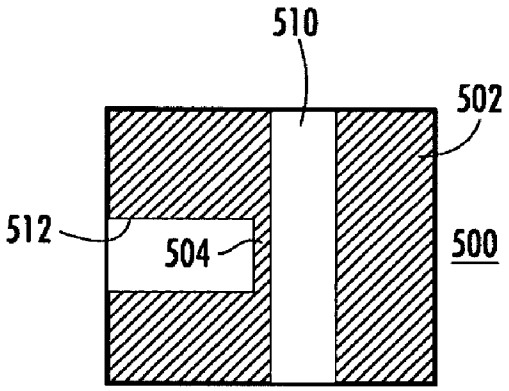


FIG. 5A

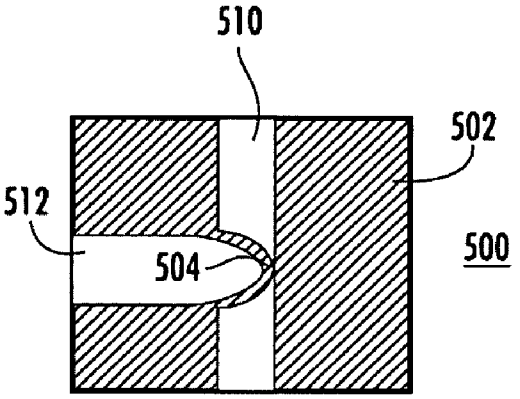


FIG. 5B

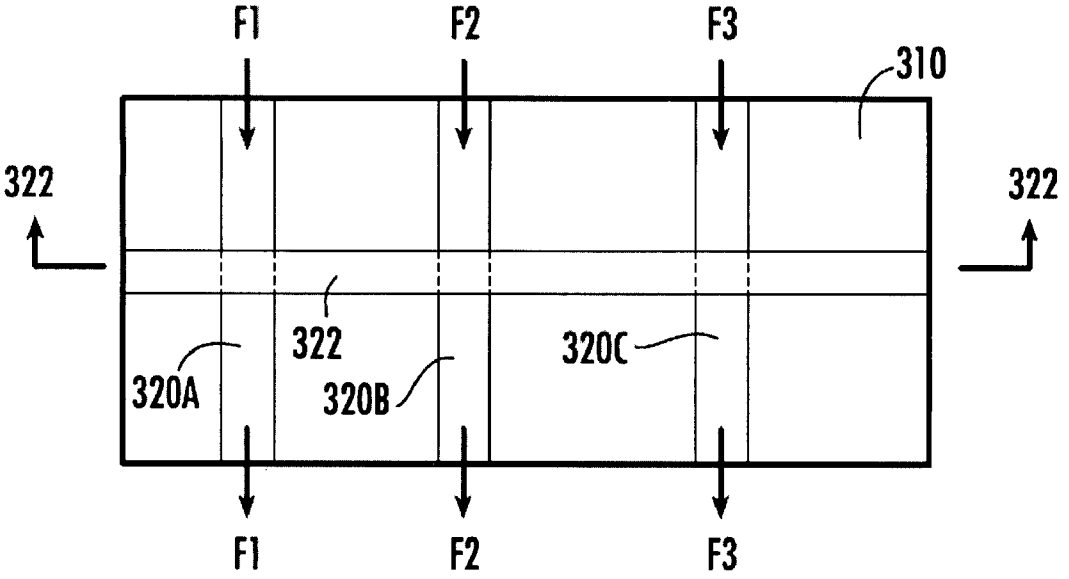

F1
F2
F3
310
322
322
322
320A
320B
320C
F1
F2
F3

FIG. 6A

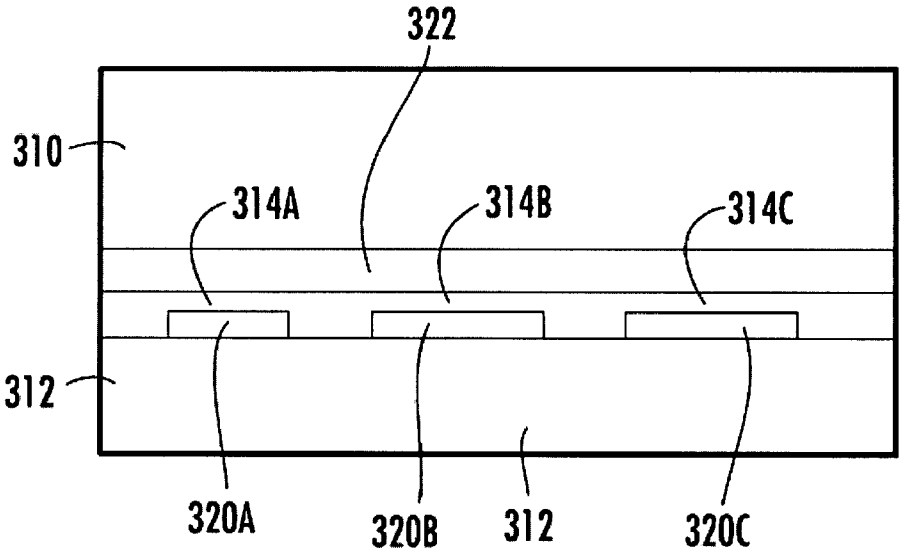

322
310
314A
314B
314C
312
320A
320B
312
320C

FIG. 6B

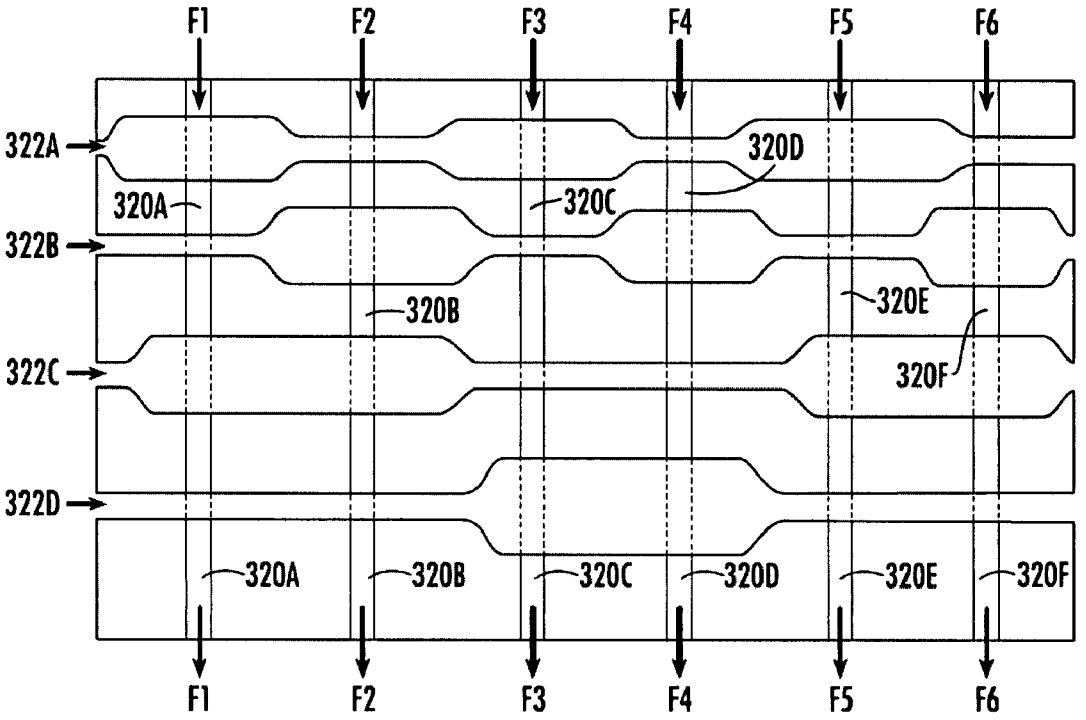

F1
F2
F3
F4
F5
F6
322A
322B
322C
322D
320A
320B
320C
320D
320E
320F

FIG. 7

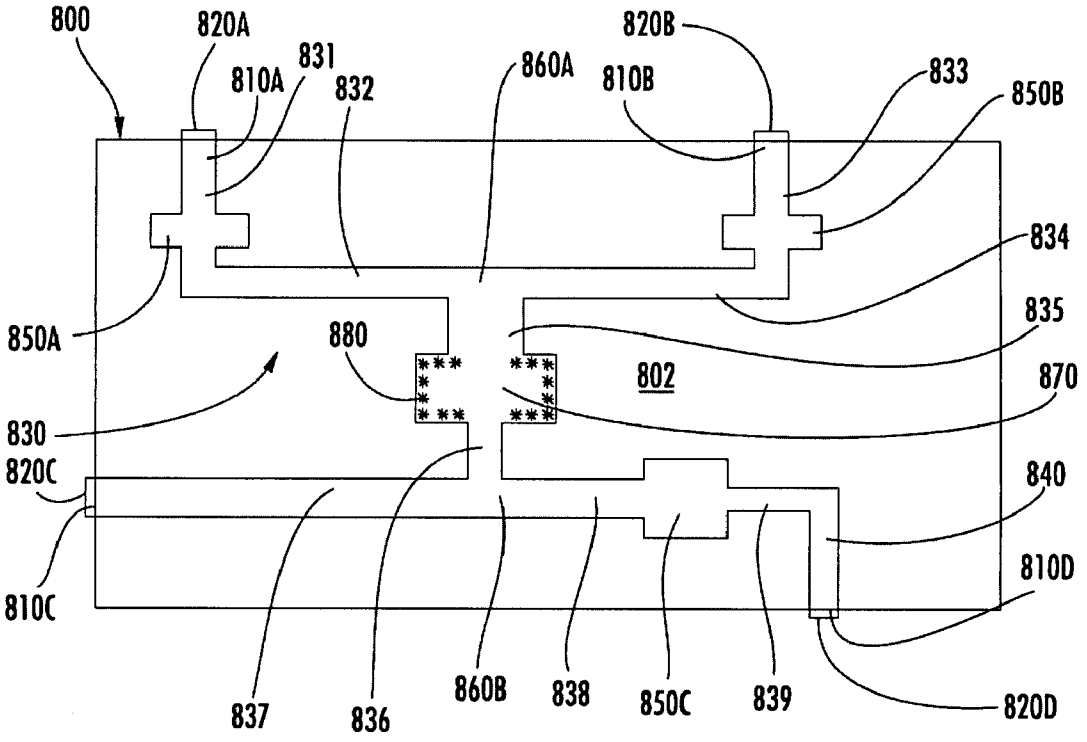

800
820A
831
810A
832
860A
820B
810B
833
850B
834
835
850A
880
802
870
830
820C
840
810C
810D
837
836
860B
838
850C
839
820D

FIG. 8

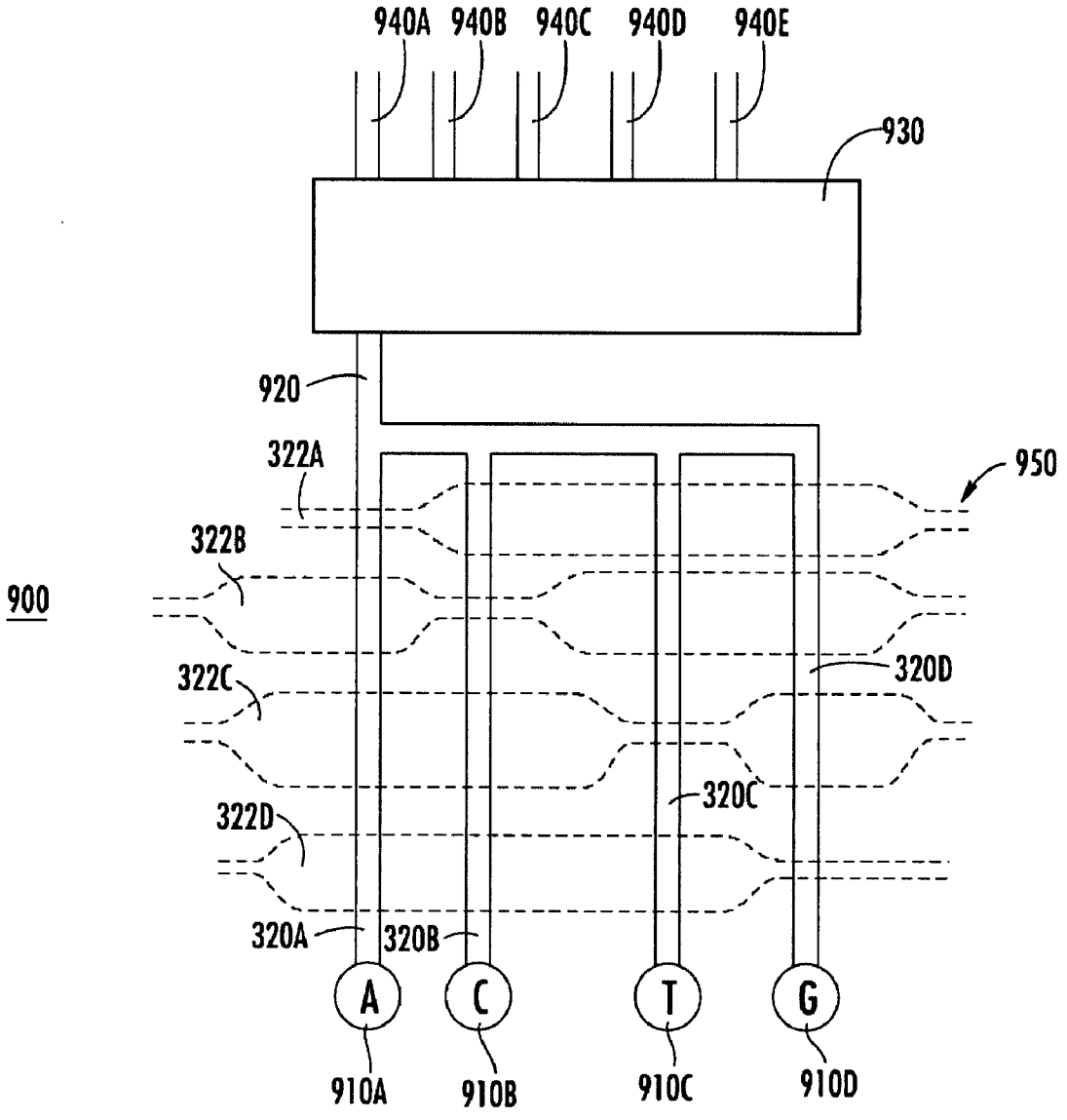

940A
940B
940C
940D
940E
930
920
322A
950
322B
900
322C
320D
320C
322D
320A
320B
A
C
T
G
910A
910B
910C
910D

FIG. 9

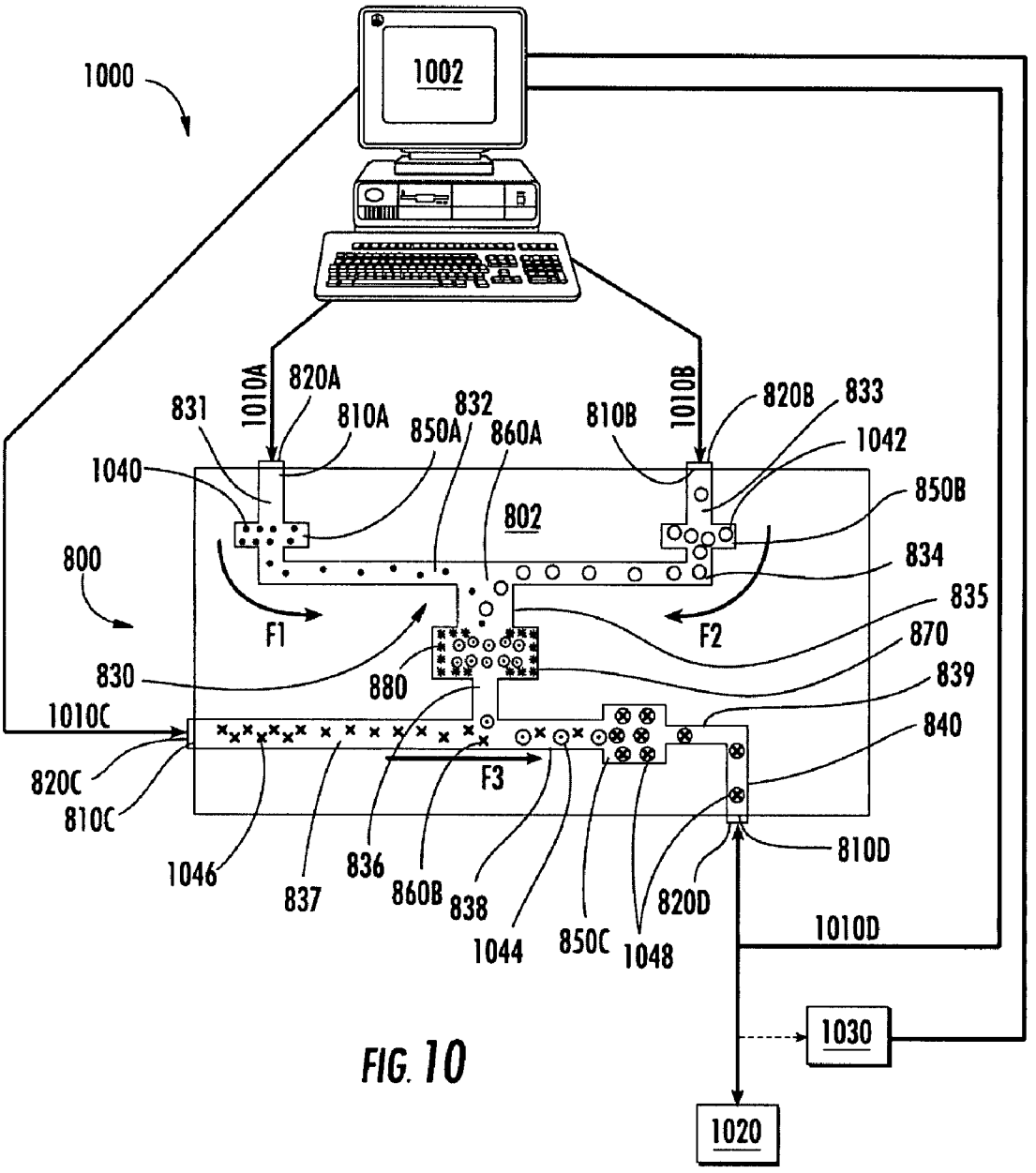

1000
1002
1010A
820A
831
810A
832
850A
860A
810B
1010B
820B
833
1042
1040
850B
802
800
834
F1
F2
835
870
830
880
839
1010C
840
820C
F3
810C
1046
837
836
860B
838
1044
850C
1048
820D
810D
1010D
1030
1020

FIG. 10

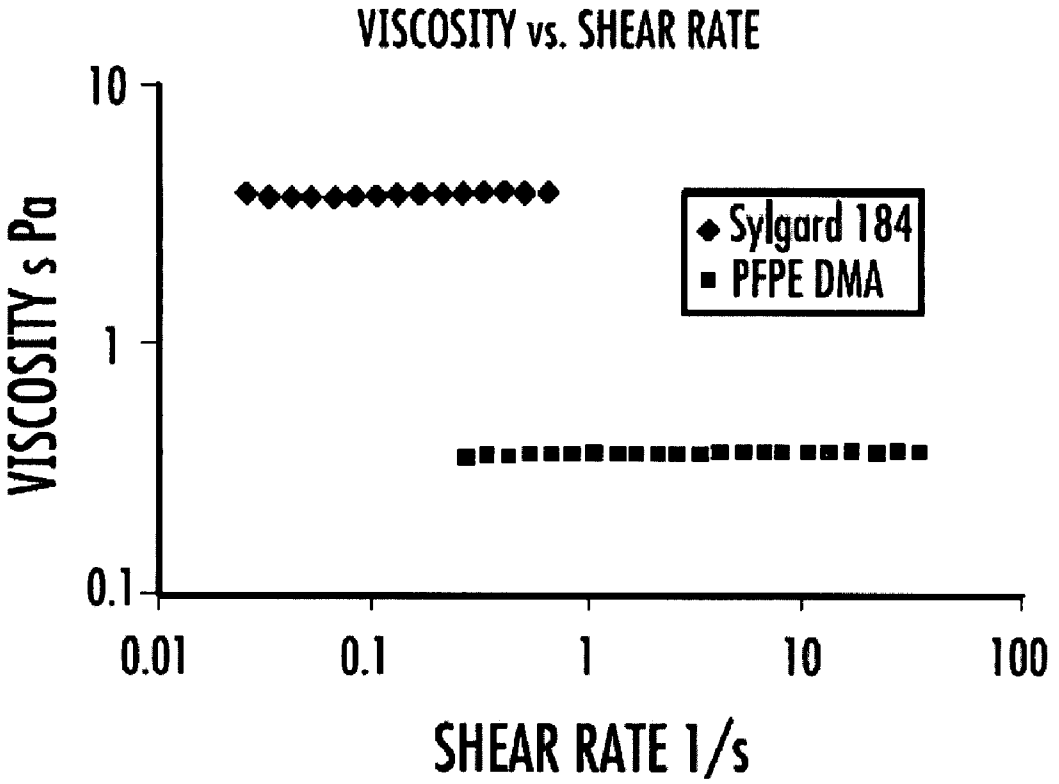

VISCOSITY vs. SHEAR RATE
VISCOSITY s Pa
10
1
0.1
0.01
0.1
1
10
100
SHEAR RATE 1/s
Sylgard 184
PFPE DMA

FIG. 11

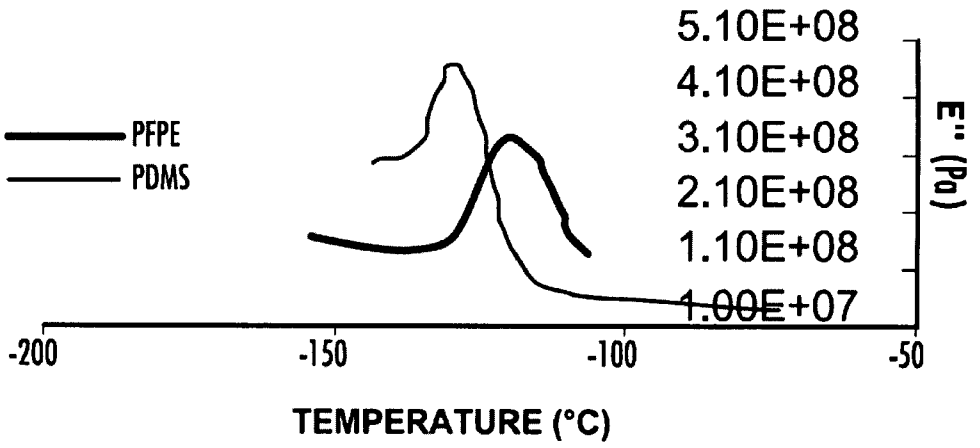

PFPE
PDMS
5.10E+08
4.10E+08
3.10E+08
2.10E+08
1.10E+08
1.00E+07
E'' (Pa)
-200
-150
-100
-50
TEMPERATURE (°C)

FIG. 12

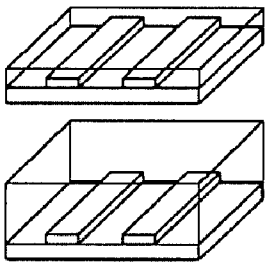


FIG. 13A

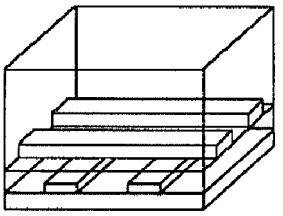


FIG. 13B

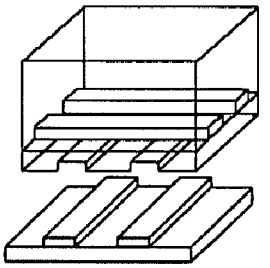


FIG. 13C

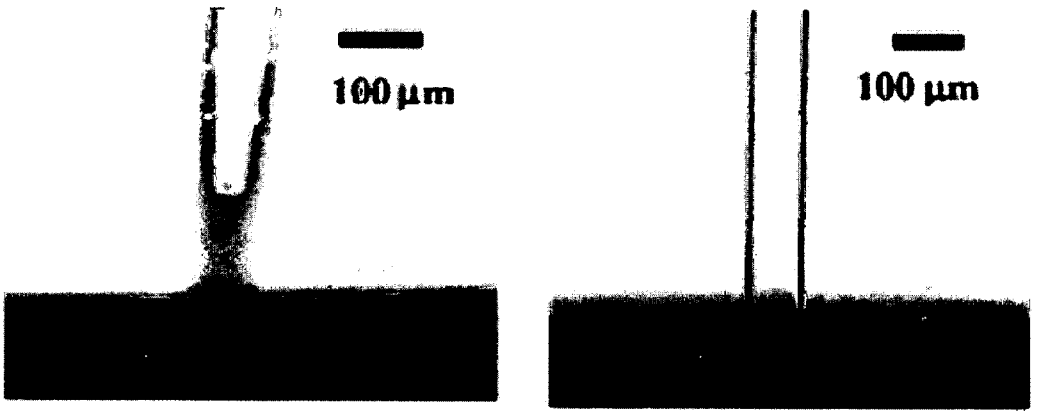


FIG. 14

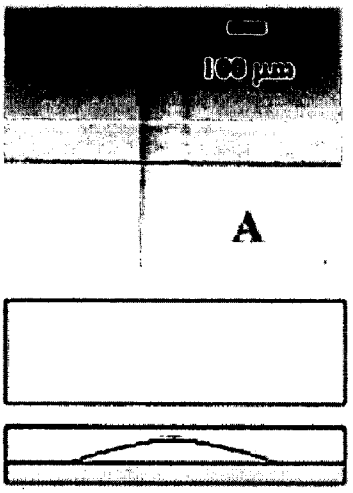


FIG. 15A

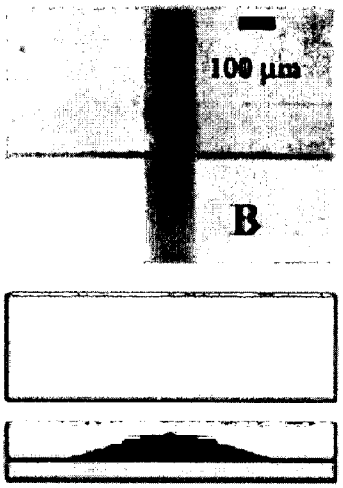


FIG. 15B

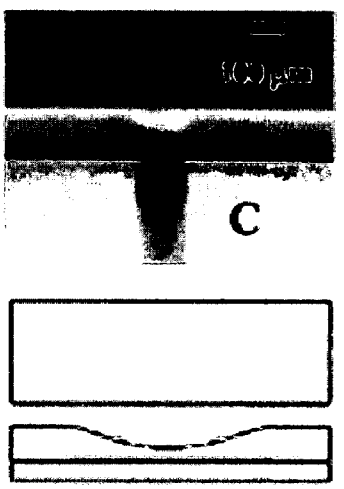


FIG. 15C

PHOTOCURABLE PERFLUOROPOLYETHERS FOR USE AS NOVEL MATERIALS IN MICROFLUIDIC DEVICES

RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 10/572,764, filed Mar. 21, 2006, which is a 371 application of PCT International Patent Application Serial No. PCT/US04/031274, filed on Sep. 23, 2004, the disclosure of each of which is incorporated herein by reference in its entirety, which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/505,384, filed Sep. 23, 2003, and U.S. Provisional Patent Application Ser. No. 60/524,788, filed Nov. 21, 2003, the disclosure of each of which is incorporated herein by reference in their entireties.

GOVERNMENT INTEREST

[0002] A portion of this invention was made with U.S. Government support from the Office of Naval Research Grant No. N00014-02-1-0185. The U.S. Government has certain rights to that portion of the invention.

TECHNICAL FIELD

[0003] The use of a photocurable perfluoropolyether (PFPE) material for fabricating a solvent-resistant PFPE-based microfluidic device, methods of flowing a material and performing a chemical reaction in a solvent-resistant PFPE-based microfluidic device, and the solvent-resistant PFPE-based microfluidic devices themselves.

ABBREVIATIONS

[0004] aL=atoliters
[0005] ° C.=degrees Celsius
[0006] cm=centimeters
[0007] cSt=centistokes
[0008] DBTDA=dibutyltin diacetate
[0009] DMA=dimethacrylate
[0010] DMPA=2,2-dimethoxy-2-phenylacetophenone
[0011] DMTA=dynamic mechanical thermal analysis
[0012] EIM=2-isocyanatoethyl methacrylate
[0013] fL=femtoliters
[0014] Freon 113=1,1,2-trichlorotrifluoroethane
[0015] g=grams
[0016] h=hours
[0017] Hz=hertz
[0018] kHz=kilohertz
[0019] kPa=kilopascals
[0020] MHz=megahertz
[0021] min minutes
[0022] mL=milliliters
[0023] mm=millimeters
[0024] mmol=millimoles
[0025] mN=milli-Newton
[0026] m.p. melting point
[0027] nL=nanoliters
[0028] nm=nanometers
[0029] PDMS=polydimethylsiloxane
[0030] PFPE=perfluoropolyether
[0031] pL=picoliters
[0032] psi=pounds per square inch
[0033] s=seconds
[0034] Tg=glass transition temperature
[0035] μL=microliters
[0036] μm=micrometers
[0037] UV=ultraviolet
[0038] w=watts
[0039] ZDOL=poly(tetrafluoroethylene oxide-co-difluoromethylene oxide)α,ωdiol

BACKGROUND

[0040] Microfluidic devices developed in the early 1990s were fabricated from hard materials, such as silicon and glass, using photolithography and etching techniques. See Ouellette, J., *The Industrial Physicist* 2003, August/September, 14-17; Scherer, A., et al., *Science* 2000, 290, 1536-1539. Photolithography and etching techniques, however, are costly and labor intensive, require clean-room conditions, and pose several disadvantages from a materials standpoint. For these reasons, soft materials have emerged as alternative materials for microfluidic device fabrication. The use of soft materials has made possible the manufacture and actuation of devices containing valves, pumps, and mixers. See, e.g., Ouellette, J., *The Industrial Physicist* 2003, August/September, 14-17; Scherer, A., et al., Science 2000, 290, 1536-1539; Unger, M. A., et al., *Science* 2000, 288, 113-116; McDonald, J. C., et al., *Acc. Chem. Res.* 2002, 35, 491-499; and Thorsen, T., et al., *Science* 2002, 298, 580-584. For example, one such microfluidic device allows for control over flow direction without the use of mechanical valves. See Zhao, B., et al., *Science* 2001, 291, 1023-1026.

[0041] The increasing complexity of microfluidic devices has created a demand to use such devices in a rapidly growing number of applications. To this end, the use of soft materials has allowed microfluidics to develop into a useful technology that has found application in genome mapping, rapid separations, sensors, nanoscale reactions, ink-jet printing, drug delivery, Lab-on-a-Chip, in vitro diagnostics, injection nozzles, biological studies, and drug screening. See, e.g., Ouellette, J., *The Industrial Physicist* 2003, August/September, 14-17; Scherer, A. et al., *Science* 2000, 290, 1536-1539; Unger, M. A., et al., *Science* 2000, 288, 113-116; McDonald, J. C., et al., *Acc. Chem. Res.* 2002, 35, 491-499; Thorsen. T., et al., *Science* 2002, 298, 580-584; and Liu. J. et al., *Anal. Chem.* 2003, 75, 4718-4723.

[0042] Poly(dimethylsiloxane) (PDMS) is the soft material of choice for many microfluidic device applications. See Scherer, A. et al., *Science* 2000, 290, 1536-1539; Unger, M. A., et al., *Science* 2000, 288, 113-116; McDonald, J. C., et al., *Acc. Chem. Res.* 2002, 35, 491-499; Thorsen, T., et al., *Science* 2002, 298, 580-584; and Liu, J., et al., *Anal. Chem.* 2003, 75, 4718-4723. A PDMS material offers numerous attractive properties in microfluidic applications. Upon cross-linking, PDMS becomes an elastomeric material with a low Young's modulus, e.g., approximately 750 kPa. See Unger, M. A., et al., *Science* 2000, 288, 113-116. This property allows PDMS to conform to surfaces and to form reversible seals. Further, PDMS has a low surface energy, e.g., approximately 20 erg/cm^2, which can facilitate its release from molds after patterning. See Scherer. A., et al., *Science* 2000, 290, 1536-1539; McDonald, J. C., et al., *Acc. Chem. Res.* 2002, 35, 491-499.

[0043] Another important feature of PDMS is its outstanding gas permeability. This property allows gas bubbles within the channels of a microfluidic device to permeate out of the device. This property also is useful in sustaining cells and microorganisms inside the features of the microfluidic device. The nontoxic nature of silicones, such as PDMS, also

is beneficial in this respect and allows for opportunities in the realm of medical implants. McDonald, J. C., et al., *Acc. Chem. Res.* 2002, 35, 491-499.

[0044] Many current PDMS microfluidic devices are based on Sylgard® 184 (Dow Corning, Midland, Mich., United States of America). Sylgard® 184 is cured thermally through a platinum-catalyzed hydrosilation reaction. Complete curing of Sylgard® 184 can take as long as five hours. The synthesis of a photocurable PDMS material, however, with mechanical properties similar to that of Sylgard® 184 for use in soft lithography recently has been reported. See Choi. K. M., et al., *J. Am. Chem. Soc.* 2003, 125, 4060-4061.

[0045] Despite the aforementioned advantages, PDMS suffers from a drawback in microfluidic applications in that it swells in most organic solvents. Thus, PDMS-based microfluidic devices have a limited compatibility with various organic solvents. See Lee, J. N., et al., *Anal. Chem.* 2003, 75, 6544-6554. Among those organic solvents that swell PDMS are hexanes, ethyl ether, toluene, dichloromethane, acetone, and acetonitrile. See Lee, J. N., et al., *Anal. Chem.* 2003, 75, 6544-6554. The swelling of a PDMS microfluidic device by organic solvents can disrupt its micron-scale features, e.g., a channel or plurality of channels, and can restrict or completely shut off the flow of organic solvents through the channels. Thus, microfluidic applications with a PDMS-based device are limited to the use of fluids, such as water, that do not swell PDMS. As a result, those applications that require the use of organic solvents likely will need to use microfluidic systems fabricated from hard materials, such as glass and silicon. See Lee, J. N., et al., *Anal. Chem.* 2003, 75, 6544-6554. This approach, however, is limited by the disadvantages of fabricating microfluidic devices from hard materials.

[0046] Moreover, PDMS-based devices and materials are notorious for not being adequately inert enough to allow them to be used even in aqueous-based chemistries. For example, PDMS is susceptible to reaction with weak and strong acids and bases. PDMS-based devices also are notorious for containing extractables, in particular extractable oligomers and cyclic siloxanes, especially after exposure to acids and bases. Because PDMS is easily swollen by organics, hydrophobic materials, even those hydrophobic materials that are slightly soluble in water, can partition into PDMS-based materials used to construct PDMS-based microfluidic devices.

[0047] Thus, an elastomeric material that exhibits the attractive mechanical properties of PDMS combined with a resistance to swelling in common organic solvents would extend the use of microfluidic devices to a variety of new chemical applications that are inaccessible by current PDMS-based devices. Accordingly, the approach demonstrated by the presently disclosed subject matter uses an elastomeric material, more particularly a photocurable perfluoropolyether (PFPE) material, which is resistant to swelling in common organic solvents to fabricate a microfluidic device.

[0048] Photocurable PFPE materials represent a unique class of fluoropolymers that are liquids at room temperature, exhibit low surface energy, low modulus, high gas permeability, and low toxicity with the added feature of being extremely chemically resistant. See Scheirs, J., *Modern Fluoropolymers*; John Wiley & Sons, Ltd.: New York, 1997; pp 435-485. Further, PFPE materials exhibit hydrophobic and lyophobic properties. For this reason, PFPE materials are often used as lubricants on high-performance machinery operating in harsh conditions. The synthesis and solubility of PFPE materials in supercritical carbon dioxide has been reported. See Bunyard, W., et al., *Macromolecules* 1999, 32, 8224-8226.

[0049] The presently disclosed subject matter describes the use of a photocurable perfluoropolyether as a material for fabricating a solvent-resistant microfluidic device. The use of a photocurable perfluoropolyether as a material for fabricating a microfluidic device addresses the problems associated with swelling in organic solvents exhibited by microfluidic devices made from other polymeric materials, such as PDMS. Accordingly, PFPE-based microfluidic devices can be used to control the flow of a small volume of a fluid, such as an organic solvent, and to perform microscale chemical reactions that are not amenable to other polymeric microfluidic devices.

SUMMARY

[0050] The presently disclosed subject matter describes the use of a photocurable PFPE material for fabricating a solvent-resistant microfluidic device. More particularly, in some embodiments, the presently disclosed subject matter describes a method of forming a patterned layer of a photocured PFPE material. In some embodiments, the method comprises coating a substrate, such as an etched silicon wafer, with a perfluoropolyether precursor and photocuring the perfluoropolyether precursor to form a patterned layer of a photocured perfluoropolyether.

[0051] In some embodiments, the presently disclosed subject matter describes a method of forming a multilayer patterned photocured perfluoropolyether material. In some embodiments, the method comprises overlaying a first patterned layer of the photocured perfluoropolyether on a second patterned layer of the photocured perfluoropolyether, wherein the patterns of the first and second layers of the photocured perfluoropolyether are aligned in a predetermined alignment, and then exposing the first and the second layers of the photocured perfluoropolyether to ultraviolet radiation for a period of time. This curing step causes the two layers to adhere to another, thereby creating a seal between the two patterned layers of the photocured perfluoropolyether.

[0052] In some embodiments, the multilayer patterned perfluoropolyether structure comprises a plurality of microscale channels, which can further comprise an integrated network of microscale channels. Accordingly, in some embodiments, the presently disclosed subject matter describes a method of flowing a material through an integrated network of microscale channels. In some embodiments, the method of flowing a material comprises actuating a valve structure within the microscale channels. In some embodiments, the method of flowing a material comprises a side-actuated valve structure. In some embodiments, the method of flowing a material comprises flow channels of different shapes and dimensions. In some embodiments, the method of flowing a material comprises actuating multiple valve structures simultaneously to control the flow through a multiplexed network of microscale channels.

[0053] In some embodiments, the presently disclosed subject matter describes a method of performing a chemical reaction in a microfluidic device, wherein the method comprises contacting a first reagent and a second reagent in the microfluidic device to form a reaction product. In some embodiments, the first reagent and the second reagent are independently selected from one of a nucleotide and a polynucleotide, wherein the reaction product comprises a polynucleotide. In some embodiments, the polynucleotide is

DNA. In some embodiments, the presently disclosed subject matter describes a method of incorporating a microfluidic device into an integrated reaction or flow system.

[0054] Further, in some embodiments, the presently disclosed subject matter describes a method of screening a sample for a characteristic. In some embodiments, the presently disclosed subject matter describes a method of dispensing a material. In some embodiments, the presently disclosed subject matter describes a method of separating a material.

[0055] Certain objects of the presently disclosed subject matter having been stated hereinabove, which are addressed in whole or in part by the presently disclosed subject matter, other aspects and objects will become evident as the description proceeds when taken in connection with the accompanying Drawings and Examples as best described herein below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0056] FIGS. **1**A-**1**C are a series of schematic end views depicting the formation of a patterned layer in accordance with the presently disclosed subject matter.

[0057] FIGS. **2**A-**2**D are a series of schematic end views depicting the formation of a microfluidic device comprising two patterned layers in accordance with the presently disclosed subject matter.

[0058] FIG. **3**A is a cross-sectional view of a PFPE-based microfluidic device showing an open flow channel.

[0059] FIG. **3**B is a cross-sectional view of a PFPE-based microfluidic device showing a substantially closed flow channel.

[0060] FIG. **4**A is a cross-sectional view of a rectangular flow channel.

[0061] FIG. **4**B is a cross-sectional view of a flow channel having a curved upper surface.

[0062] FIG. **5**A is a plan view illustrating a side-actuated valve structure in an open position.

[0063] FIG. **5**B is a plan view illustrating a side-actuated valve structure in a closed position.

[0064] FIG. **6**A is a top schematic view of one control channel actuating multiple flow channels simultaneously.

[0065] FIG. **6**B is a sectional elevation view along control channel **322** as shown in FIG. **6**A.

[0066] FIG. **7** is a schematic illustration of a multiplexed system adapted to permit flow through various channels.

[0067] FIG. **8** is a schematic plan view of a microfluidic device in accordance with the presently disclosed subject matter.

[0068] FIG. **9** is a schematic of an integrated microfluidic system for biopolymer synthesis.

[0069] FIG. **10** is schematic view of a system for flowing a solution or conducting a chemical reaction in a microfluidic device in accordance with the presently disclosed subject matter. The microfluidic device **800** is depicted as a schematic plan view as shown in FIG. **8**.

[0070] FIG. **11** is a plot of the viscosity versus the shear rate for Sylgard® 184 and perfluoropolyether dimethacrylate (PFPE DMA) materials.

[0071] FIG. **12** represents the dynamic mechanical thermal analysis (DMTA) traces of crosslinked polydimethylsiloxane (PDMS) and perfluoropolyether (PFPE) materials showing maxima in the loss modulus as a function of temperature.

[0072] FIGS. **13**A-**13**C depict a representative device fabrication procedure. FIG. **13**A: A thin layer (20 μm) and a thick layer (5 mm) of PFPE DMA are partially cured. FIG. **13**B: The thick layer is peeled off its wafer, rotated 90°, and placed on top of the thin layer. The entire device is then fully cured to adhere the two layers together. FIG. **13**C: The device is peeled off the wafer.

[0073] FIG. **14** depicts a photograph of a dyed solution of dichloromethane, acetonitrile, and methanol entering a PFPE device channel (left). In comparison, no solution entered a PDMS channel of the same size due to swelling (right).

[0074] FIGS. **15**A-**15**C depict a photograph illustrating the actuation of a valve. FIG. **15**A: Top-down view of the channels containing no solvent. The channels on the thin layer (fluid) run vertically, while those on the thick layer (air) run horizontally. FIG. **15**B: Thin-layer channel filled with a dyed solution of acetonitrile, dichloromethane, and methanol. FIG. **15**C: Valve actuation produced by introducing 25 psi of air into the thick-layer channel. A schematic representation of the valve is presented beneath each picture.

DETAILED DESCRIPTION

[0075] The presently disclosed subject matter will now be described more fully hereinafter with reference to the accompanying Drawings and Examples, in which representative embodiments are shown. The presently disclosed subject matter can, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the embodiments to those skilled in the art.

[0076] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this presently described subject matter belongs. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety.

[0077] Throughout the specification and claims, a given chemical formula or name shall encompass all optical and stereoisomers, as well as racemic mixtures where such isomers and mixtures exist.

I. DEFINITIONS

[0078] As used herein, the term "microfluidic device" generally refers to a device through which materials, particularly fluid borne materials, such as liquids, can be transported, in some embodiments on a micro-scale, and in some embodiments on a nano-scale. Thus, the microfluidic devices described by the presently disclosed subject matter can comprise microscale features, nanoscale features, and combinations thereof.

[0079] Accordingly, a microfluidic device typically comprises structural or functional features dimensioned on the order of a millimeter-scale or less, which are capable of manipulating a fluid at a flow rate on the order of a microliter/min or less. Typically, such features include, but are not limited to channels, fluid reservoirs, reaction chambers, mixing chambers, and separation regions. In some examples, the channels include at least one cross-sectional dimension that is in a range of from about 0.1 μm to about 500 μm. The use of dimensions on this order allows the incorporation of a greater number of channels in a smaller area, and utilizes smaller volumes of fluids.

[0080] A microfluidic device can exist alone or can be a part of a microfluidic system which, for example and without limitation, can include: pumps for introducing fluids, e.g.,

samples, reagents, buffers and the like, into the system and/or through the system; detection equipment or systems; data storage systems; and control systems for controlling fluid transport and/or direction within the device, monitoring and controlling environmental conditions to which fluids in the device are subjected, e.g., temperature, current, and the like.

[0081] As used herein, the terms "channel," "microscale channel," and "microfluidic channel" are used interchangeably and can mean a recess or cavity formed in a material by imparting a pattern from a patterned substrate into a material or by any suitable material removing technique, or can mean a recess or cavity in combination with any suitable fluid-conducting structure mounted in the recess or cavity, such as a tube, capillary, or the like.

[0082] As used herein, the terms "flow channel" and "control channel" are used interchangeably and can mean a channel in a microfluidic device in which a material, such as a fluid, e.g., a gas or a liquid, can flow through. More particularly, the term "flow channel" refers to a channel in which a material of interest, e.g., a solvent or a chemical reagent, can flow through. Further, the term "control channel" refers to a flow channel in which a material, such as a fluid, e.g., a gas or a liquid, can flow through in such a way to actuate a valve or pump.

[0083] As used herein, the term "valve" unless otherwise indicated refers to a configuration in which two channels are separated by an elastomeric segment, e.g., a PFPE segment, that can be deflected into or retracted from one of the channels, e.g., a flow channel, in response to an actuation force applied to the other channel, e.g., a control channel.

[0084] As used herein, the term "pattern" can mean a channel or a microfluidic channel or an integrated network of microfluidic channels, which, in some embodiments, can intersect at predetermined points. A pattern also can comprise one or more of a microscale fluid reservoir, a microscale reaction chamber, a microscale mixing chamber, and a microscale separation region.

[0085] As used herein, the term "intersect" can mean to meet at a point, to meet at a point and cut through or across, or to meet at a point and overlap. More particularly, as used herein, the term "intersect" describes an embodiment wherein two channels meet at a point, meet at a point and cut through or across one another, or meet at a point and overlap one another. Accordingly, in some embodiments, two channels can intersect, i.e., meet at a point or meet at a point and cut through one another, and be in fluid communication with one another. In some embodiments, two channels can intersect, i.e., meet at a point and overlap one another, and not be in fluid communication with one another, as is the case when a flow channel and a control channel intersect.

[0086] As used herein, the term "communicate" (e.g., a first component "communicates with" or "is in communication with" a second component) and grammatical variations thereof are used to indicate a structural, functional, mechanical, electrical, optical, or fluidic relationship, or any combination thereof, between two or more components or elements. As such, the fact that one component is said to communicate with a second component is not intended to exclude the possibility that additional components can be present between, and/or operatively associated or engaged with, the first and second components.

[0087] In referring to the use of a microfluidic device for handling the containment or movement of fluid, the terms "in", "on", "into", "onto", "through", and "across" the device generally have equivalent meanings.

[0088] As used herein, the term "monolithic" refers to a structure comprising or acting as a single, uniform structure.

[0089] As used herein, the term "non-biological organic materials" refers to organic materials, i.e., those compounds having covalent carbon-carbon bonds, other than biological materials. As used herein, the term "biological materials" includes nucleic acid polymers (e.g., DNA, RNA) amino acid polymers (e.g., enzymes) and small organic compounds (e.g., steroids, hormones) wherein the small organic compounds have biological activity, especially biological activity for humans or commercially significant animals, such as pets and livestock, and where the small organic compounds are used primarily for therapeutic or diagnostic purposes. While biological materials are of interest with respect to pharmaceutical and biotechnological applications, a large number of applications involve chemical processes that are enhanced by other than biological materials, i.e., non-biological organic materials.

[0090] Following long-standing patent law convention, the terms "a", "an", and "the" refer to "one or more" when used in this application, including the claims. Thus, for example, reference to "a microfluidic channel" includes a plurality of such microfluidic channels, and so forth.

II. METHOD OF MAKING A MICROFLUIDIC DEVICE FROM A PHOTOCURABLE PERFLUOROPOLYETHER MATERIAL

[0091] The presently disclosed subject matter describes a method of making a microfluidic device from a photocurable perfluoropolyether (PFPE) material. More particularly, the presently disclosed subject matter describes a method of forming a patterned layer of a photocurable PFPE material. A microfluidic device comprising at least one patterned layer of the photocurable PFPE material also is disclosed.

II.A. Method of Forming a Patterned Layer of a Photocurable Perfluoropolyether Material

[0092] In some embodiments, the presently disclosed subject matter provides a method of forming a patterned layer of a photocurable PFPE material. Referring now to FIGS. **1**A-**1**C, a schematic representation of an embodiment of the presently disclosed subject matter is shown. A substrate S having a patterned surface PS comprising a raised protrusion P is depicted. Accordingly, the patterned surface PS of the substrate S comprises at least one raised protrusion P which forms the shape of a pattern. In some embodiments, the patterned surface PS of the substrate S comprises a plurality of raised protrusions P which form a complex pattern.

[0093] As best seen in FIG. **1**B, a polymeric precursor PP is disposed on patterned surface PS of substrate S. Polymeric precursor PP can comprise a perfluoropolyether. As shown in FIG. **1**B, ultraviolet light UV is applied to provide photocuring of polymeric precursor PP. Upon curing of polymeric precursor PP, a patterned layer PL of a photocured perfluoropolyether as shown in FIG. **1**C is formed.

[0094] As shown in FIG. **1**C, the patterned layer PL of the photocured perfluoropolyether comprises a recess R that is formed in the bottom surface of the patterned layer PL. The dimensions of recess R correspond to the dimensions of the raised protrusion P of patterned surface PS of substrate S. In some embodiments, recess R comprises at least one channel

CH, which in some embodiments of the presently disclosed subject matter comprises a microscale channel. Patterned layer PL is removed from patterned surface PS of substrate S to yield microfluidic device MD.

[0095] Accordingly, in some embodiments, a method of forming a patterned layer of a photocured perfluoropolyether comprises:

[0096] (a) providing a substrate, wherein the substrate comprises a patterned surface;

[0097] (b) contacting a perfluoropolyether precursor with the patterned surface of the substrate; and

[0098] (c) photocuring the perfluoropolyether precursor to form a patterned layer of a photocured perfluoropolyether.

[0099] In some embodiments, a method of forming a patterned layer of a photocured perfluoropolyether comprises:

[0100] (a) coating the patterned surface of the substrate with a blend of a perfluoropolyether precursor and a photoinitiator to form a coated, patterned substrate;

[0101] (b) exposing the coated, patterned substrate to ultraviolet radiation for a period of time to form a layer of a photocured perfluoropolyether on the patterned substrate; and

[0102] (c) removing the layer of the photocured perfluoropolyether from the patterned substrate to produce a patterned layer of the photocured perfluoropolyether.

[0103] In some embodiments, the patterned substrate comprises an etched silicon wafer. In some embodiments, the patterned substrate comprises a photoresist patterned substrate. For the purposes of the presently disclosed subject matter, the patterned substrate can be fabricated by any of the processing methods known in the art, including, but not limited to, photolithography, electron beam lithography, and ion milling.

Krytox® (DuPont, Wilmington, Del., United States of America). A similar polymer is produced by the UV catalyzed photo-oxidation of hexafluoropropene (Fomblin® Y) (Solvay Solexis, Brussels, Belgium). Further, a linear polymer (Fomblin® Z) (Solvay) is prepared by a similar process, but utilizing tetrafluoroethylene. Finally, a fourth polymer (Demnum®) (Daikin Industries, Ltd., Osaka, Japan) is produced by polymerization of tetrafluorooxetane followed by direct fluorination. Structures for these fluids are presented in Table I. Table II contains property data for some members of the PFPE class of lubricants. In addition to these commercially available PFPE fluids, a new series of structures are being prepared by direct fluorination technology. Representative structures of these new PFPE materials appear in Table III. Of the abovementioned PFPE fluids, only Krytox® and Fomblin® Z have been extensively used in applications. See Jones, W. R., Jr., The Properties of Perfluoropolyethers Used for Space Applications, NASA Technical Memorandum 106275 (July 1993), which is incorporated herein by reference in its entirety. Accordingly, the use of such PFPE materials is provided in the presently disclosed subject matter.

TABLE I

Names and Chemical Structures of Commercial PFPE Fluids

Name	Structure
Demnum ®	$C_3F_7O(CF_2CF_2CF_2O)_xC_2F_5$
Krytox ®	$C_3F_7O[CF(CF_3)CF_2O]_xC_2F_5$
Fomblin ® Y	$C_3F_7O[CF(CF_3)CF_2O]_x(CF_2O)_yC_2F_5$
Fomblin ® Z	$CF_3O(CF_2CF_2O)_x(CF_2O)_yCF_3$

TABLE II

PFPE Physical Properties

Lubricant	Average Molecular Weight	Viscosity at 20° C., (cSt)	Viscosity Index	Pour Point, ° C.	Vapor Pressure, Torr 20° C.	Vapor Pressure, Torr 100° C.
Fomblin ® Z-25	9500	255	355	−66	2.9×10^{-12}	1×10^{-8}
Krytox ® 143AB	3700	230	113	−40	1.5×10^{-6}	3×10^{-4}
Krytox ® 143AC	6250	800	134	−35	2×10^{-8}	8×10^{-6}
Demnum ® S-200	8400	500	210	−53	1×10^{-10}	1×10^{-7}

[0104] In some embodiments, the coating step comprises a spin-coating step. In some embodiments, the perfluoropolyether precursor comprises poly(tetrafluoroethylene oxide-co-difluoromethylene oxide)α,ω diol. In some embodiments, the photoinitiator comprises 2,2-dimethoxy-2-phenyl acetophenone. In some embodiments, the photocured perfluoropolyether comprises a perfluoropolyether dimethacrylate. In some embodiments, the photocured perfluoropolyether comprises a perfluoropolyether distyrenic.

[0105] As would be recognized by one of ordinary skill in the art, perfluoropolyethers (PFPEs) have been in use for over 25 years for many applications. Commercial PFPE materials are made by polymerization of perfluorinated monomers. The first member of this class was made by the cesium fluoride catalyzed polymerization of hexafluoropropene oxide (HFPO) yielding a series of branched polymers designated as

TABLE III

Names and Chemical Structures of Representative PFPE Fluids

Name	Structure[a]
Perfluoropoly(methylene oxide) (PMO)	$CF_3O(CF_2O)_xCF_3$
Perfluoropoly(ethylene oxide) (PEO)	$CF_3O(CF_2CF_2O)_xCF_3$
Perfluoropoly(dioxolane) (DIOX)	$CF_3O(CF_2CF_2OCF_2O)_xCF_3$
Perfluoropoly(trioxocane) (TRIOX)	$CF_3O[(CF_2CF_2O)_2CF_2O]_xCF_3$

[a]wherein x is any integer.

[0106] In some embodiments, the ultraviolet radiation has a wavelength of about 365 nanometers. In some embodiments, the period of time the coated, patterned substrate is exposed to the ultraviolet radiation ranges from about one second to about 300 seconds. In some embodiments, the period of time

the coated, patterned substrate is exposed to the ultraviolet radiation ranges from about one second to about 100 seconds. In some embodiments, the period of time the coated, patterned substrate is exposed to the ultraviolet radiation is about six seconds. In some embodiments, the period of time the coated, patterned substrate is exposed to the ultraviolet radiation is about 60 seconds.

[0107] In some embodiments, the patterned layer of the photocured perfluoropolyether is between about 0.1 micrometers and about 100 micrometers thick. In some embodiments, the patterned layer of the photocured perfluoropolyether is between about 0.1 millimeters and about 10 millimeters thick. In some embodiments, the patterned layer of the photocured perfluoropolyether is between about one micrometer and about 50 micrometers thick. In some embodiments, the patterned layer of the photocured perfluoropolyether is about 20 micrometers thick. In some embodiments, the patterned layer of the photocured perfluoropolyether is about 5 millimeters thick.

[0108] In some embodiments, the patterned layer of the photocured perfluoropolyether comprises a plurality of microscale channels. In some embodiments, the channels have a width ranging from about 0.01 μm to about 1000 μm; a width ranging from about 0.05 μm to about 1000 μm; and/or a width ranging from about 1 μm to about 1000 μm. In some embodiments, the channels have a width ranging from about 1 μm to about 500 μm; a width ranging from about 1 μm to about 250 μm; and/or a width ranging from about 10 μm to about 200 μm. Exemplary channel widths include, but are not limited to, 0.1 μm, 1 μm, 2 μm, 5 μm, 10 μm, 20 μm, 30 μm, 40 μm, 50 μm, 60 μm, 70 μm, 80 μm, 90 μm, 100 μm, 110 μm, 120 μm, 130 μm, 140 μm, 150 μm, 160 μm, 170 μm, 180 μm, 190 μm, 200 μm, 210 μm, 220 μm, 230 μm, 240 μm, and 250 μm.

[0109] In some embodiments, the channels have a depth ranging from about 1 μm to about 1000 μm; and/or a depth ranging from about 1 μm to 100 μm. In some embodiments, the channels have a depth ranging from about 0.01 μm to about 1000 μm; a depth ranging from about 0.05 μm to about 500 μm; a depth ranging from about 0.2 μm to about 250 μm; a depth ranging from about 1 μm to about 100 μm; a depth ranging from about 2 μm to about 20 μm; and/or a depth ranging from about 5 μm to about 10 μm. Exemplary channel depths include, but are not limited to 0.01 μm, 0.02 μm, 0.05 μm, 0.1 μm, 0.2 μm, 0.5 μm, 1 μm, 2 μm, 3 μm, 4 μm, 5 μm, 7.5 μm, 10 μm, 12.5 μm, 15 μm, 17.5 μm, 20 μm, 22.5 μm, 25 μm, 30 μm, 40 μm, 50 μm, 75 μm, 100 μm, 150 μm, 200 μm, and 250 μm.

[0110] In some embodiments, the channels have a width-to-depth ratio ranging from about 0.1:1 to about 100:1. In some embodiments, the channels have a width-to-depth ratio ranging from about 1:1 to about 50:1. In some embodiments, the channels have a width-to-depth ratio ranging from about 2:1 to about 20:1. In some embodiments, the channels have a width-to-depth ratio ranging from about 3:1 to about 15:1. In some embodiments, the channels have a width-to-depth ratio of about 10:1.

[0111] One of ordinary skill in the art would recognize that the dimensions of the channels of the presently disclosed subject matter are not limited to the exemplary ranges described hereinabove and can vary in width and depth to affect the magnitude of force required to flow a material through the channel and/or to actuate a valve to control the flow of the material therein. Further, as will be described in more detail herein below, channels of greater width are contemplated for use as a fluid reservoir, a reaction chamber, a mixing channel, a separation region and the like.

II.B. Method of Forming a Multilayer Patterned Photocurable Perfluoropolyether Material

[0112] In some embodiments, the presently disclosed subject matter describes a method of forming a multilayer patterned photocured perfluoropolyether material. In some embodiments, the multilayer patterned photocured perfluoropolyether material is used to fabricate a monolithic PFPE-based microfluidic device.

[0113] Referring now to FIGS. **2**A-**2**D, a schematic representation of the preparation of an embodiment of the presently disclosed subject matter is shown. Patterned layers PL**1** and PL**2** are provided, each of which comprise a perfluoropolyether material. In this example, each of the patterned layers PL**1** and PL**2** comprise channels CH. In this embodiment of the presently disclosed subject matter, channels CH are microscale channels. In patterned layer PL**1**, the channels are represented by a dashed line, i.e., in shadow, in FIGS. **2**A-**2**C. Patterned layer PL**2** is overlaid on patterned layer PL**1** in a predetermined alignment. In this example, the predetermined alignment is such that channels CH in patterned layer PL**1** and PL**2** are substantially perpendicular to each other. In some embodiments, as depicted in FIGS. **2**A-**2**D, patterned layer PL**1** is overlaid on nonpatterned layer NPL. Nonpatterned layer NPL can comprise a perfluoropolyether.

[0114] Continuing with reference to FIGS. **2**A-**2**D, patterned layers PL**1** and PL**2**, and in some embodiments nonpatterned layer NPL, are exposed to ultraviolet light UV. The exposing of layers PL**1**, PL**2**, and, in some embodiments nonpatterned layer NPL, to ultraviolet light UV provides for the adhering of patterned layers PL**1** and PL**2** to each other, and in some embodiments, patterned layer PL**1** to nonpatterned layer NPL, as shown in FIGS. **2**C and **2**D. The resulting microfluidic device MD comprises an integrated network IN of microscale channels CH which intersect at predetermined intersecting points IP, as best seen in the cross-section provided in FIG. **2**D. Also shown in FIG. **2**D is membrane M comprising the top surface of channels CH of patterned layer PL**1** which separates channel CH of patterned layer PL**2** from channels CH of patterned layer PL**1**.

[0115] Continuing with reference to FIGS. **2**A-**2**C, in some embodiments, patterned layer PL**2** comprises a plurality of holes, and the holes are designated input aperture IA and output aperture OA. In some embodiments, the holes, e.g., input aperture IA and output aperture OA are in fluid communication with channels CH. In some embodiments, as shown in FIGS. **5**A and **5**B, and as will be discussed in more detail herein below, the holes comprise a side-actuated valve structure comprising a thin membrane of PFPE material which can be actuated to restrict the flow in an abutting channel.

[0116] Accordingly, in some embodiments, the presently disclosed subject matter describes a method of forming a multilayer patterned photocured perfluoropolyether material, the method comprising:

[0117] (a) overlaying a first patterned layer of the photocured perfluoropolyether on a second patterned layer of the photocured perfluoropolyether, wherein the patterns of the first and second layers of the photocured perfluoropolyether are aligned in a predetermined alignment; and

[0118] (b) exposing the first and the second layers of the photocured perfluoropolyether to ultraviolet radiation for a period of time.

[0119] In some embodiments, the first patterned layer of photocured PFPE material is cast at such a thickness to impart a degree of mechanical stability to the PFPE structure. Accordingly, in some embodiments, the first patterned layer of the photocured PFPE material is about 50 μm to several centimeters thick. In some embodiments, the first patterned layer of the photocured PFPE material is between 50 μm and about 10 millimeters thick. In some embodiments, the first patterned layer of the photocured PFPE material is 5 mm thick. In some embodiments, the first patterned layer of PFPE material is about 4 mm thick. Further, in some embodiments, the thickness of the first patterned layer of PFPE material ranges from about 0.1 μm to about 10 cm; from about 1 μm to about 5 cm; from about 10 μm to about 2 cm; and from about 100 μm to about 10 mm.

[0120] In some embodiments, the second patterned layer of the photocured PFPE material is between about 1 micrometer and about 100 micrometers thick. In some embodiments, the second patterned layer of the photocured PFPE material is between about 1 micrometer and about 50 micrometers thick. In some embodiments, the second patterned layer of the photocured material is about 20 micrometers thick.

[0121] Although FIGS. **2**A-**2**C and FIG. **13** disclose the formation of a microfluidic device wherein two patterned layers of PFPE material are combined, in some embodiments of the presently disclosed subject matter it is possible to form a microfluidic device comprising one patterned layer and one non-patterned layer of PFPE material. Thus, the first patterned layer can comprise a microscale channel or an integrated network of microscale channels and then the first patterned layer can be overlaid on top of the non-patterned layer and adhered to the non-patterned layer using a photocuring step, such as application of ultraviolet light as disclosed herein, to form a monolithic structure comprising enclosed channels therein.

[0122] Accordingly, in some embodiments, a first and a second patterned layer of photocured perfluoropolyether material, or alternatively a first patterned layer of photocured perfluoropolyether material and a nonpatterned layer of photocured perfluoropolyether material, adhere to one another, thereby forming a monolithic PFPE-based microfluidic device.

III. METHOD OF DIRECTING THE FLOW OF A MATERIAL THROUGH A PFPE-BASED MICROFLUIDIC DEVICE

[0123] In some embodiments, the presently disclosed subject matter describes a method of directing the flow of a material through a PFPE-based microfluidic device. In some embodiments, the method of directing the flow of a material through a PFPE-based microfluidic device comprises actuating a valve structure or a plurality of valve structures within the microfluidic device. In some embodiments, the valve structure comprises a portion of the microfluidic channel itself. In some embodiments, the valve structure further comprises a side-actuated valve.

III.A. Method of Actuating a Valve Structure within a PFPE-Based Microfluidic Device

[0124] In some embodiments, the method of actuating a valve structure within a PFPE-based microfluidic device comprises closing a first flow channel by applying pressure to an abutting second flow channel (or "control channel"), thereby deflecting a thin membrane of PFPE material separating the two channels into the first flow channel. FIGS. **3**A and **3**B together show the closing of a first flow channel by pressurizing a second flow channel. Referring now to FIG. **3**A, a front sectional view of a monolithic PFPE-based microfluidic device **300** comprising a multilayer patterned PFPE material **310** adhered to planar nonpatterned PFPE layer **312** is shown. A first flow channel **320** and a second flow channel **322** are separated by membrane **314**, which forms the top of first flow channel **320** and the bottom of second flow channel **322**. As depicted in FIG. **3**A, flow channel **320** is open.

[0125] Referring now to FIG. **3**B, pressurization of flow channel **322** (either by a gas or a fluid introduced therein) causes membrane **314** to deflect downward, thereby restricting flow F, as shown in FIG. **3**A, passing through flow channel **320**. Accordingly, by varying the pressure in channel **322**, an actuable valving system is provided such that flow channel **320** can be substantially opened or substantially closed or in an intermediate open or closed position by deflecting membrane **314** as desired. For illustration purposes only, channel **320** in FIG. **3**B is shown in a "substantially closed" position, rather than a "fully closed" position.

[0126] In some embodiments, the membrane **314** of PFPE material separating overlapping channels **320** and **322** has a thickness between about 0.01 μm and 1000 μm, about 0.05 μm to 500 μm, 0.2 μm to 250 μm, 1 μm to 100 μm, 2 μm to 50 μm, and 5 μm to 40 μm. Exemplary membrane thicknesses include, but are not limited to, 0.01 μm, 0.02 μm, 0.03 μm, 0.05 μm, 0.1 μm, 0.2 μm, 0.3 μm, 0.5 μm, 1 μm, 2 μm, 3 μm, 5 μm, 7.5 μm, 10 μm, 12.5 μm, 15 μm, 17.5 μm, 20 μm, 22.5 μm, 25 μm, 30 μm, 40 μm, 50 μm, 75 μm, 100 μm, 150 μm, 200 μm, 250 μm, 300 μm, 400 μm, 500 μm, 750 μm, and 1000 μm.

[0127] Because such valves are actuated by moving a portion of the channels themselves (i.e., deflecting membrane **314**) and do not require additional components, valves and pumps produced by this technique have a zero dead volume, and switching valves made by this technique have a dead volume approximately equal to the active volume of the valve, for example about 100 μm×100 μm×10 μm=100 pL. Such dead volumes and areas consumed by the moving membrane are approximately two orders of magnitude smaller than known conventional microvalves. Smaller and larger valves are provided in the presently disclosed subject matter, including, but not limited to, valves comprising a dead volume ranging from 1 aL to 1 μL; 100 aL to 100 nL; 1 fL to 1 mL; 100 fL to 1 mL; and 1 pL to 100 pL.

[0128] The small volume of materials, such as a fluid, capable of being delivered by pumps and valves in accordance with the presently disclosed subject matter represent a substantial advantage over pumps and valves known in the art. For example, the smallest known volume of a fluid capable of being manually metered is about 0.1 μL. Further, the smallest known volume of a fluid capable of being metered by automated systems is about 1 μL. Using pumps and valves in accordance with the presently disclosed subject matter, a volume of a fluid comprising 10 nL or smaller can be metered and dispensed. The accurate metering of extremely small volumes of fluid enabled by the presently disclosed subject matter can be extremely valuable in a large number of biological applications, including microscale synthesis of biological materials, such as DNA, and diagnostic tests and assays.

[0129] As described in U.S. Pat. No. 6,408,878 to Unger et al., which is incorporated herein by reference in its entirety, the deflection of an elastomeric membrane in response to a pressure is a function of: the length, width, and thickness of the membrane, the flexibility of the membrane, e.g., as provided by its Young's modulus, and the applied actuation force. Because each of these parameters will vary depending on the dimensions and physical composition of a particular elastomeric device, e.g., a PFPE device in accordance with the presently disclosed subject matter, a wide range of membrane thicknesses, channel widths, and actuation forces are provided.

[0130] Pressure can be applied to actuate the membrane of the device by passing a fluid or a gas, such as air, through, for example, a first piece of tubing connected to a second, narrower piece of tubing, such as a hypodermic tubing, e.g., a metal hypodermic needle, wherein the metal hypodermic needle is placed into contact with the flow channel by insertion into the PFPE block in a direction normal to the flow channel.

[0131] Accordingly, in some embodiments, the method of actuating a PFPE-based microfluidic device further comprises forming a plurality of holes in at least one patterned layer of the photocured perfluoropolyether material. In some embodiments, as shown in FIG. **2**A, at least one of the plurality of holes comprises an inlet aperture IA. In some embodiments, as also shown in FIG. **2**A, at least one of the plurality of holes comprises an outlet aperture OA.

[0132] Further, such an embodiment addresses a number of problems posed by connecting a conventional microfluidic device to an external fluid source. One such problem is the fragility of the connection between the microfluidic device and the external fluid source. Conventional microfluidic devices comprise hard, inflexible materials, such as silicon, to which tubing providing a connection to an external element must be joined. The rigidity of conventional materials creates a physical stress at the points of contact with the external tubing, rendering conventional microfluidic devices prone to fracture and leakage at these contact points.

[0133] By contrast, the PFPE material of the presently described subject matter is flexible and can be penetrated for external connection by a rigid tube, such as a metal hypodermic needle, comprising a hard material. For example, in a PFPE structure fabricated using the method shown in FIGS. **1** and **2**, a hole extending from the exterior surface of the structure into the flow channel, as shown in FIGS. **2**A-**2**C, can be made by penetrating the external surface of the patterned layer of PFPE material with the metal hypodermic needle after the upper layer of PFPE material has been removed from the mold (as shown in FIG. **1**C) and before this layer has been bonded to the second patterned layer of PFPE material (as shown in FIG. **2**A-**2**C).

[0134] Between these steps, a portion of the flow channel is exposed to the user's view and is accessible to insertion of the hypodermic needle and proper positioning of the hole. Following completion of fabrication of the device, the metal hypodermic needle is inserted into the hole to complete the fluid connection to the external fluid source. Moreover, the PFPE material of the presently disclosed subject matter will flex in response to physical strain at the point of contact with an external connection, rendering the external physical connection more robust. This flexibility substantially reduces the chance of leakage or fracture of the presently described microfluidic device.

[0135] Another disadvantage of conventional microfluidic devices is the difficulty in establishing an effective seal between the device and its connections to an external fluid flow. Because of the narrow diameter of the channels that is typical of these microfluidic devices, achieving even moderate rates of fluid flow can require input high pressures. Accordingly, unwanted leakage at the point of contact between the device and an external connection can result. The flexibility of the PFPE material from which the presently described microfluidic device is fabricated aids in preventing leakage related to high input pressures. More particularly, the flexible PFPE material conforms to the shape of inserted tubing to form a substantially pressure resistant seal.

[0136] While control of the flow of material through the device has so far been described using an applied gas pressure, other fluids can be used. A gas is compressible, and thus experiences some finite delay between the time of application of pressure by, for example, an external solenoid valve and the time that this pressure is experienced by the membrane separating the flow channels of the microfluidic device. Accordingly, in some embodiments of the presently disclosed subject matter, pressure is applied from an external source to a non-compressible fluid, such as water or a hydraulic oil, resulting in a near-instantaneous transfer of applied pressure to the membrane. If the displaced volume of the membrane is large or the flow channel is narrow, higher viscosity of the control fluid can contribute to delay in actuation. Therefore, the optimal medium for transferring pressure will depend on the particular application and device configuration. Accordingly, the use of both gaseous and liquid media to actuate the deflectable membrane is provided by the presently disclosed subject matter.

[0137] In some embodiments, the external pressure is applied by a pump and tank system through a pressure regulator and external valve. As will be understood by one of ordinary skill in the art, other methods of applying external pressure are provided by the presently disclosed subject matter, including gas tanks, compressors, piston systems, and columns of liquid. Also provided for use in the presently disclosed subject matter are naturally occurring pressure sources, such as those found inside living organisms, including blood pressure, gastric pressure, the pressure present in the cerebro-spinal fluid, pressure present in the intra-ocular space, and the pressure exerted by muscles during normal flexure. Other methods of regulating external pressure also are provided by the presently disclosed subject matter, including miniature valves, pumps, macroscopic peristaltic pumps, pinch valves, and other types of fluid regulating equipment such as is known in the art.

[0138] In some embodiments, the response of the microfluidic valves in accordance with the presently disclosed subject matter is nearly linear over a substantial portion of its range of travel, with minimal hysteresis. See U.S. Pat. No. 6,408,878 to Unger et al., which is incorporated herein by reference in its entirety. Accordingly, the valves in accordance with the presently disclosed subject matter are ideally suited for microfluidic metering and fluid control.

[0139] While the valves and pumps of the presently disclosed subject matter do not require linear actuation to open and close, a linear response facilitates the use of the valves as metering devices. In some embodiments, the opening of the valve is used to control a flow rate by being partially actuated to a known degree of closure. Linear valve actuation also facilitates the determination of the amount of actuation force

required to close the valve to a desired degree of closure. Another benefit of linear actuation is that the force required for valve actuation can be determined from the pressure in the flow channel. Accordingly, if actuation is linear, an increased pressure in the flow channel can be countered by adding the same pressure (force per unit area) to the actuated portion of the valve. Thus, high pressures in the flow channel (i.e., back pressure) can be countered by increasing the actuation pressure.

[0140] Linearity of the response of a valve depends on the structure, composition, and method of actuation of the valve structure. Further, whether linearity is a desirable characteristic in a valve depends on the application. Therefore, both linearly and non-linearly actuatable valves are provided in the presently disclosed subject matter, and the pressure ranges over which a valve is linearly actuatable will vary with the specific embodiment.

[0141] In addition to the pressure-based actuation systems described hereinabove, electrostatic and magnetic actuation systems also are provided by the presently disclosed subject matter. For example, electrostatic actuation can be accomplished by forming oppositely charged electrodes (which will tend to attract one another when a voltage differential is applied to them) directly into the monolithic PFPE structure. Referring again to FIG. **3**A, a first electrode **330**A (shown in phantom) can be positioned on (or in) membrane **314** and a second electrode **330**B (also shown in phantom) can be positioned on (or in) planar nonpatterned PFPE layer **312**. When electrodes **330**A and **330**B are charged with opposite polarities, an attractive force between the two electrodes will cause membrane **314** to deflect downwardly, thereby closing flow channel **320**.

[0142] For the membrane electrode to be sufficiently conductive to support electrostatic actuation, but not so mechanically stiff so as to impede the membrane's motion, a sufficiently flexible electrode must be provided in or over membrane **314**. Such a sufficiently flexible electrode can be provided by depositing a thin metallization layer on membrane **314**, doping the polymer with conductive material, or making the surface layer out of a conductive material.

[0143] In some embodiments, the electrode present at the deflecting membrane is provided by a thin metallization layer, which can be provided, for example, by sputtering a thin layer of metal, such as 20 nm of gold. In addition to the formation of a metallized membrane by sputtering, other metallization approaches, such as chemical epitaxy, evaporation, electroplating, and electroless plating, also are available. Physical transfer of a metal layer to the surface of the elastomer also is available, for example by evaporating a metal onto a flat substrate to which it adheres poorly, and then placing the elastomer onto the metal and peeling the metal off of the substrate.

[0144] The conductive electrode **330**A also can be formed by depositing carbon black (e.g., Vulcan® XC72R Cabot Corporation, Boston, Mass., United States of America) on the elastomer surface. Alternatively, the electrode **330**A can be formed by constructing the entire structure **300** out of elastomer doped with conductive material (i.e., carbon black or finely divided metal particles). The electrode also can be formed by electrostatic deposition, or by a chemical reaction that produces carbon.

[0145] The lower electrode **330**B, which is not required to move, can be either a compliant electrode as described above, or a conventional electrode, such as evaporated gold, a metal plate, or a doped semiconductor electrode.

[0146] In some embodiments, magnetic actuation of the flow channels can be achieved by fabricating the membrane separating the flow channels with a magnetically polarizable material, such as iron, or a permanently magnetized material, such as polarized NdFeB.

[0147] In embodiments wherein the membrane is fabricated with a magnetically polarizable material, the membrane can be actuated by attraction in response to an applied magnetic field. In embodiments wherein the membrane is fabricated with a material capable of maintaining permanent magnetization, the material can first be magnetized by exposure to a sufficiently high magnetic field, and then actuated either by attraction or repulsion in response to the polarity of an applied inhomogeneous magnetic field.

[0148] The magnetic field causing actuation of the membrane can be generated in a variety of ways. In some embodiments, the magnetic field is generated by a small inductive coil formed in or proximate to the elastomer membrane. The actuation effect of such a magnetic coil is localized, thereby allowing actuation of an individual pump and/or valve structure. In some embodiments, the magnetic field is generated by a larger, more powerful source, in which case actuation is not localized and can actuate multiple pump and/or valve structures simultaneously.

[0149] It is further possible to combine pressure actuation with electrostatic or magnetic actuation. More particularly, a bellows structure in fluid communication with a recess and/or channel could be electrostatically or magnetically actuated to change the pressure in the recess and/or channel and thereby actuate a membrane structure adjacent to the recess and/or channel.

[0150] In addition to electrical or magnetic actuation as described above, electrolytic and electrokinetic actuation systems also are provided by the presently disclosed subject matter. For example, in some embodiments, actuation pressure on the membrane arises from an electrolytic reaction in a recess and/or channel overlying the membrane. In such an embodiment, electrodes present in the recess and/or channel apply a voltage across an electrolyte in the recess and/or channel. This potential difference causes electrochemical reaction at the electrodes and results in the generation of gas species, giving rise to a pressure differential in the recess and/or channel.

[0151] In some embodiments, actuation pressure on the membrane arises from an electrokinetic fluid flow in the control channel. In such an embodiment, electrodes present at opposite ends of the control channel apply a potential difference across an electrolyte present in the control channel. Migration of charged species in the electrolyte to the respective electrodes gives rise to a pressure differential.

[0152] In some embodiments, it is possible to actuate the device by causing a fluid flow in the control channel based upon the application of thermal energy, either by thermal expansion or by production of a gas from a liquid. Similarly, chemical reactions generating gaseous products can produce an increase in pressure sufficient for membrane actuation.

III.B. Method of Actuating a Valve Structure within a PFPE-Based Microfluidic Device Comprising Flow Channels of Different Cross Sectional Sizes and Shapes

[0153] In some embodiments, the presently disclosed subject matter describes flow channels comprising different cross sectional sizes and shapes, offering different advantages

depending on their desired application, in particular, advantages with regard to sealing a flow channel. For example, the cross sectional shape of the lower flow channel can have a curved upper surface, either along its entire length or in the region disposed under an upper cross channel.

[0154] Referring now to FIG. **4**A, a cross sectional view similar to that of FIG. **3**A of flow channels **320** and **322** is shown. In this embodiment, flow channel **320** is rectangular in cross sectional shape. In some embodiments, as shown in FIG. **4**B, the cross-section of flow channel **320** has a curved upper surface as depicted by **320**A.

[0155] Referring again to FIG. **4**A, when flow channel **322** is pressurized, the membrane portion **314** separating flow channels **320** and **322** will move downwardly to the successive positions shown by the dotted lines **314**A, **314**B, **314**C, **314**D, and **314**E. In some cases, incomplete sealing can occur at the edges of rectangular flow channel **320** and adjacent planar nonpatterned PFPE layer **312**.

[0156] Referring again to FIG. **4**B, flow channel **320**A has a curved upper surface **314**A. When flow channel **322** is pressurized, membrane portion **314** will move downwardly to the successive positions shown by dotted lines **314**A**2**, **314**A**3**, **314**A**4** and **314**A**5**, with edge portions of the membrane moving first into the flow channel, followed by top membrane portions. An advantage of having such a curved upper surface at membrane **314** is that a more complete seal will be provided when flow channel **322** is pressurized. More particularly, the upper surface of flow channel **320**A will provide a continuous contacting edge against nonpatterned PFPE layer **312**, thereby avoiding the incomplete contact seen between membrane **314** and the bottom of flow channel **320** in FIG. **4**A.

[0157] Another advantage of having a curved upper flow channel surface at membrane **314** is that the membrane can more readily conform to the shape and volume of the flow channel in response to actuation. More particularly, when a rectangular flow channel is employed, the entire perimeter (2× flow channel height, plus the flow channel width) must be forced into the flow channel. When a curved flow channel is used, a smaller perimeter of material (only the semi-circular arched portion) must be forced into the channel. In this manner, the membrane requires less change in perimeter for actuation and is therefore more responsive to an applied actuation force to close the flow channel.

[0158] In some embodiments, (not illustrated), the bottom of flow channel **320** is rounded such that its curved surface mates with the curved upper surface **314**A as seen in FIG. **4**B described above.

[0159] In summary, the actual conformational change experienced by the membrane upon actuation will depend on the configuration of the particular PFPE structure. More particularly, the conformational change will depend on the length, width, and thickness profile of the membrane, its attachment to the remainder of the structure, and the height, width, and shape of the flow and control channels and the material properties of the PFPE material used. The conformational change also can depend on the method of actuation, as actuation of the membrane in response to an applied pressure will vary somewhat from actuation in response to a magnetic or electrostatic force.

[0160] Moreover, the desired conformational change in the membrane will also vary depending on the particular application for the PFFE structure. In the embodiments described above, the valve can either be open or closed, with metering to control the degree of closure of the valve.

[0161] Many membrane thickness profiles and flow channel cross-sections are provided by the presently disclosed subject matter, including rectangular, trapezoidal, circular, ellipsoidal, parabolic, hyperbolic, and polygonal, as well as sections of the aforementioned shapes. More complex cross-sectional shapes, such as the embodiment with protrusions discussed immediately above or an embodiment comprising concavities in the flow channel, also are provided by the presently disclosed subject matter.

III.C. Method of Actuating a Side-Actuated Valve Structure

[0162] In some embodiments, the presently disclosed subject matter comprises a side-actuated valve structure. Referring now to FIGS. **5**A and **5**B, FIG. **5**A shows a side-actuated valve structure **500** in an unactuated position. Flow channel **510** is formed in PFPE layer **502**. Control channel **512** abutting flow channel **510** also is formed in PFPE layer **502**. In some embodiments, control channel **512** comprises a "hole" formed by, for example, puncturing the PFPE layer with a hypodermic needle as described hereinabove. Control channel **512** is separated from flow channel **510** by PFPE membrane portion **504**. A second PFPE layer (not shown) is bonded over bottom PFPE layer **502**, for example by photocuring, to enclose flow channel **510** and control channel **512**.

[0163] FIG. **5**B shows side-actuated valve structure **500** in an actuated position. In response to pressure, or other actuation technique, within control channel **512**, membrane **504** deforms into flow channel **510**, blocking flow channel **510**. Upon release of pressure within control channel **512**, membrane **504** relaxes back into control channel **512** and open flow channel **510**.

[0164] While a side-actuated valve structure actuated in response to pressure is shown in FIGS. **5**A and **5**B, a side-actuated valve in accordance with the presently disclosed subject matter is not limited to this configuration. In some embodiments, the PFPE membrane portion located between the abutting flow and control channels is manipulated by electric or magnetic fields, as described hereinabove.

III.D. Method of Actuating an Integrated Network of Microscale Channels Comprising a PFPE-Based Microfluidic Device

[0165] In some embodiments, the predetermined alignment of the first and second layers of the photocured perfluoropolyether material forms a plurality of microscale channels. In some embodiments, the plurality of microscale channels comprises an integrated network of microscale channels. In some embodiments, the microscale channels of the integrated network intersect at predetermined intersecting points.

[0166] Referring now to FIGS. **6**A and **6**B, a schematic view of a plurality of flow channels which are controllable by a single control channel is shown. This system is comprised of a plurality of single addressable on/off valves multiplexed together. More particularly, a plurality of parallel flow channels **320**A, **320**B, and **320**C are provided. Flow channel **322** (i.e., a "control line") passes over flow channels **320**A, **320**B, and **320**C. Pressurization of control line **322** simultaneously shuts off flows F**1**, F**2**, and F**3** by depressing membranes **314**A, **314**B, and **314**C located at the intersections of control line **322** and flow channels **320**A, **320**B, and **320**C.

[0167] Referring now to FIG. **7**, a schematic illustration of a multiplexing system adapted to permit fluid flow through selected channels, comprised of a plurality of the single on/off valves, joined or networked together is shown. A plurality of parallel flow channels **320**A, **320**B, **320**C, **320**D, **320**E, and **320**F are positioned under a plurality of parallel control lines **322**A, **322**B, **322**C, and **322**D. Control channels **322**A, **322**B, **322**C, and **322**D are actuated to shut off fluid flows F**1**, F**2**, F**3**, F**4**, F**5**, and F**6** passing through parallel flow channels **320**A, **320**B, **320**C, **320**D, **320**E, and **320**F using any of the valving systems described above, with the following modification.

[0168] The downward deflection of membranes separating the respective flow channels from a control line passing thereabove (for example, membranes **314**A, **314**B, and **314**C in FIGS. **6**A and **6**B) depends on the membrane dimensions. Accordingly, by varying the widths of flow channel control line **322** in FIGS. **6**A and **6**B, it is possible to have a control line pass over multiple flow channels, yet only actuate (i.e., close) desired flow channels. Each of control lines **322**A, **322**B, **322**C, and **322**D have both wide and narrow portions. For example, control line **322**A is wide in locations disposed over flow channels **320**A, **320**C, and **320**E. Similarly, control line **322**B is wide in locations disposed over flow channels **320**B, **320**D and **320**F, and control line **322**C is wide in locations disposed over flow channels **320**A, **320**B, **320**E, and **320**F.

[0169] At the locations where the respective control line is wide, its pressurization causes the membrane **314** separating the flow channel and the control line (as shown in FIG. **6**B) to depress significantly into the flow channel, thereby blocking the flow passage therethrough. Conversely, in the locations where the respective control line is narrow, membrane **314** also is narrow. Accordingly, the same degree of pressurization will not result in membrane **314** becoming depressed into the flow channel **320**. Therefore, fluid passage thereunder will not be blocked.

[0170] For example, when control line **322**A is pressurized, it blocks flows F**1**, F**3**, and F**5** in flow channels **320**A, **320**C, and **320**E, respectively. Similarly, when control line **322**C is pressurized, it blocks flows F**1**, F**2**, F**5**, and F**6** in flow channels **320**A, **320**B, **320**E, and **320**F, respectively. As will be appreciated by one of ordinary skill in the art upon review of the present disclosure, more than one control line can be actuated at the same time. For example, control lines **322**A and **322**C can be pressurized simultaneously to block all fluid flow except F**4** (with control line **322**A blocking F**1**, F**3**, and F**5**; and control line **322**C blocking F**1**, F**2**, F**5**, and F**6**).

[0171] By selectively pressurizing different control lines **322**A-D both together and in various sequences, a degree of fluid flow control can be achieved. Moreover, by extending the present system to more than six parallel flow channels **320**A-F and more than four parallel control lines **322**A-D, and by varying the positioning of the wide and narrow regions of the control lines, complex fluid flow control systems can be fabricated.

IV. METHOD OF USING A PFPE-BASED MICROFLUIDIC DEVICE

[0172] In some embodiments, the presently disclosed subject matter describes a method of flowing a material and/or performing a chemical reaction in a PFPE-based microfluidic device. In some embodiments, the presently disclosed subject matter describes a method of synthesizing a biopolymer, such as DNA. In some embodiments, the presently disclosed subject matter describes a method of screening a sample for a characteristic. In some embodiments, the presently disclosed subject matter disclosed a method of dispensing a material. In some embodiments, the presently disclosed subject matter discloses a method of separating a material.

IV.A. Method of Flowing a Material and/or Performing a Chemical Reaction in a PFPE-Based Microfluidic Device

[0173] In some embodiments, the presently disclosed subject mater describes a method of flowing a material and/or performing a chemical reaction in a PFPE-based microfluidic device. Referring now to FIG. **8**, a schematic plan view of a microfluidic device of the presently disclosed subject matter is shown. The microfluidic device is referred to generally at **800**. Microfluidic device **800** comprises a patterned layer **802**, and a plurality of holes **810**A, **810**B, **810**C, and **810**D. These holes can be further described as inlet aperture **810**A, inlet aperture **810**B, and inlet aperture **810**C, and outlet aperture **810**D. Each of apertures **810**A, **810**B, **810**C, and **810**D are covered by seals **820**A, **820**B, **820**C, and **820**D, which are preferably reversible seals. Seals **820**A, **820**B, **820**C, and **820**D are provided so that materials, including but not limited to, solvents, chemical reagents, components of a biochemical system, samples, inks, and reaction products and/or mixtures of solvents, chemical reagents, components of a biochemical system, samples, inks, reaction products and combinations thereof, can be stored, shipped, or otherwise maintained in microfluidic device **800** if desired. Seals **820**A, **820**B, **820**C, and **820**D can be reversible, that is, removable, so that microfluidic device **800** can be implemented in a chemical reaction or other use and then can be resealed if desired.

[0174] Continuing with reference to FIG. **8**, in some embodiments, apertures **810**A, **810**B, and 81° C., further comprise pressure actuated valves (comprising intersecting, overlaid flow channels not shown) which can be actuated to seal the microfluidic channel associated the aperture.

[0175] Continuing with reference to FIG. **8**, patterned layer **802** of microfluidic device **800** comprises an integrated network **830** of microscale channels. Integrated network **830** thus comprises a series of fluidly connected microscale channels designated by the following reference characters: **831**, **832**, **833**, **834**, **835**, **836**, **837**, **838**, **839**, and **840**. Thus, inlet aperture **810**A is in fluid communication with microscale channel **831** which extends away from aperture **810**A and is in fluid communication with microscale channel **832** via a bend. In integrated network **830** depicted in FIG. **8**, a series of 90° bends are shown for convenience. It is noted, however, that the paths and bends provided in the channels of integrated network **830**, can encompass any desired configuration, angle, or other characteristic. Indeed, fluid reservoirs **850**A and **850**B can be provided along microscale channels **831**, **832**, **833**, and **834**, respectively, if desired. As shown in FIG. **8**, fluid reservoirs **850**A and **850**B comprise at least one dimension that is greater than a dimension of the channels that are immediately adjacent to them.

[0176] Continuing, then, with reference to FIG. **8**, microscale channels **832** and **834** intersect at intersecting point **860**A and proceed into a single microscale channel **835**. Microscale channel **835** proceeds to a chamber **870**, which in the embodiment shown in FIG. **8**, is dimensioned to be wider than microscale channel **835**. In some embodiments, chamber **870** comprises a reaction chamber. In some embodiments, chamber **870** comprises a mixing chamber. In some embodiments, chamber **870** comprises a separation region. In some embodi-

ments, the separation region comprises a given dimension, e.g., length, of a channel, wherein the material is separated by charge, or mass, or combinations thereof, or any other physical characteristic wherein a separation can occur over a given dimension. In some embodiments, the separation region comprises an active material **880**. As would be understood by one of ordinary skill in the art, the term "active material" is used herein for convenience and does not imply that the material must be activated to be used for its intended purpose. In some embodiments, the active material is a chromatographic material. In some embodiments, the active material is a target material.

[0177] Continuing with FIG. **8**, it is noted that chamber **870** does not necessarily need to be of a wider dimension than an adjacent microscale channel. Indeed chamber **870** can simply comprise a given segment of a microscale channel wherein at least two materials are separated, mixed, and/or reacted. Extending from chamber **870** substantially opposite from microscale channel **835** is microscale channel **836**. Microscale channel **836** forms a T-junction with microscale channel **837** which extends away from and is in fluid communication with aperture **810**C. Thus, the junction of microscale channels **836** and **837** form intersecting point **860**B. Microscale channel **838** extends from intersecting point **860**B in a direction substantially opposite microscale channel **837** and to fluid reservoir **850**C. Fluid reservoir **850**C is dimensioned to be wider than microscale channel **838** for a predetermined length. As noted above, however, a given section of a microscale channel can act as a fluid reservoir without the need to necessarily change a dimension of the section of microscale channel. Moreover, microscale channel **838** could act as a reaction chamber in that a reagent flowing from microscale channel **837** to intersection point **860**B could react with a reagent moving from microscale channel **836** to intersection point **860**B and into microscale channel **838**.

[0178] Continuing with reference to FIG. **8**, microscale channel **839** extends from fluid reservoir **850**C substantially opposite microfluidic channel **838** and travels through a bend into microscale channel **840**. Microscale channel **840** is fluidly connected to outlet aperture **810**D. Outlet aperture **810**D can optionally be reversibly sealed via seal **820**D, as discussed above. Again, the reversible sealing of outlet aperture **810**D can be desirable in the case of an embodiment where a reaction product is formed in microfluidic device **800** and is desired to be transported to another location in microfluidic device **800**.

[0179] The flow of a material can be directed through the integrated network **830** of microscale channels, including channels, fluid reservoirs, and reaction chambers, by the method described in FIG. **7**.

[0180] Accordingly, in some embodiments, the presently disclosed subject matter comprises a method of flowing a material in a microfluidic device, the method comprising: (a) providing a microfluidic device comprising at least one patterned layer of a photocured perfluoropolyether, wherein the patterned layer of the photocured perfluoropolyether comprises at least one microscale channel; and (b) flowing a material in the microscale channel.

[0181] In some embodiments, the method comprises disposing a material in the microfluidic device. In some embodiments, as is best shown in FIG. **10** and as discussed in more detail herein below, the method comprises applying a driving force to move the material along the microscale channel. In some embodiments, the method further comprises a plurality of microscale channels. In some embodiments, the plurality of microscale channels comprises an integrated network of microscale channels. In some embodiments, the microscale channels of the integrated network intersect at predetermined points. In some embodiments, the patterned layer of the photocured perfluoropolyether comprises a plurality of holes. In some embodiments, at least one of the plurality of holes comprises an inlet aperture. In some embodiments, at least one of the plurality of holes comprises an outlet aperture. In some embodiments, the method comprises at least one pressure actuated valve, wherein the pressure actuated valve is defined by one of: (a) a microscale channel; and (b) at least one of the plurality of holes. In some embodiments, the pressure actuated valve is actuated by introducing a pressurized fluid into one of: (a) a microscale channel; and (b) at least one of the plurality of holes.

[0182] In some embodiments, the pressurized fluid has a pressure between about 10 psi and about 40 psi. In some embodiments, the pressure is about 25 psi. In some embodiments, the material comprises a fluid. In some embodiments, the fluid comprises a solvent. In some embodiments, the solvent comprises an organic solvent. In some embodiments, the material flows in a predetermined direction along the microscale channel.

[0183] Further, in some embodiments, the presently disclosed subject matter describes a method of performing a chemical reaction, the method comprising:

[0184] (a) providing a microfluidic device comprising a patterned layer of a photocured perfluoropolyether; and

[0185] (b) contacting a first reagent and a second reagent in the microfluidic device to form a reaction product.

[0186] In some embodiments, the patterned layer of the photocured perfluoropolyether comprises a plurality of microscale channels. In some embodiments, at least one of the microscale channels comprises a fluid reservoir. In some embodiments, at least one of the microscale channels comprises a fluid reaction chamber in fluid communication with the fluid reservoir.

[0187] In some embodiments, the method further comprises flowing the first reagent and the second reagent in a predetermined direction in the microfluidic device. In some embodiments, the contacting of the first reagent and the second reagent is performed in a microscale reaction chamber. In some embodiments, the method further comprises flowing the reaction product in a predetermined direction in the microfluidic device.

[0188] In some embodiments, the method further comprises recovering the reaction product. In some embodiments, the method further comprises flowing the reaction product to an outlet aperture of the microfluidic device.

[0189] In some embodiments, the method further comprises contacting the reaction product with a third reagent to form a second reaction product. In some embodiments, the first reagent and the second reagent comprise an organic solvent, including, but not limited to, hexanes, ethyl ether, toluene, dichloromethane, acetone, and acetonitrile.

IV.B. Method of Synthesizing a Biopolymer in a PFPE-Based Microfluidic Device

[0190] In some embodiments, the presently disclosed PFPE-based microfluidic device can be used in biopolymer synthesis, for example, in synthesizing oligonucleotides, proteins, peptides, DNA, and the like. In some embodiments, such biopolymer synthesis systems comprise an integrated

system comprising an array of reservoirs, fluidic logic for selecting flow from a particular reservoir, an array of channels, reservoirs, and reaction chambers in which synthesis is performed, and fluidic logic for determining into which channels the selected reagent flows.

[0191] Referring now to FIG. **9**, a plurality of reservoirs, e.g., reservoirs **910**A, **910**B, **910**C, and **910**D, have bases A, C, T, and G respectively disposed therein, as shown. Four flow channels **320**A, **320**B, **320**C, and **320**D are connected to reservoirs **910**A, **910**B, **910**C, and **910**D. Four control channels **322**A, **322**B, **322**C, and **322**D (shown in phantom) are disposed thereacross with control channel **322**A permitting flow only through flow channel **320**A (i.e., sealing flow channels **320**B, **320**C, and **320**D), when control channel **322**A is pressurized. Similarly, control channel **322**B permits flow only through flow channel **320**B when pressurized. As such, the selective pressurization of control channels **322**A, **322**B, **322**C, and **322**D sequentially selects a desired base A, C, T, and G from a desired reservoir **910**A, **910**B, **910**C, or **910**D. The fluid then passes through flow channel **920** into a multiplexed channel flow controller **930**, (including, for example, any system as shown in FIGS. **7** and **8**) which in turn directs fluid flow into one or more of a plurality of synthesis channels or reaction chambers **940**A, **940**B, **940**C, **940**D, or **940**E in which solid phase synthesis may be carried out.

[0192] In some embodiments, instead of starting from the desired base A, C, T, and G, a reagent selected from one of a nucleotide and a polynucleotide is disposed in at least one of reservoir **910**A, **910**B, **910**C, and **910**D. In some embodiments, the reaction product comprises a polynucleotide. In some embodiments, the polynucleotide is DNA.

[0193] Accordingly, after a review of the present disclosure, one of ordinary skill in the art would recognize that the presently disclosed PFPE-based microfluidic device can be used to synthesize biopolymers, as described in U.S. Pat. Nos. 6,408,878 to Unger et al. and 6,729,352 to O'Conner et al., and/or in a combinatorial synthesis system as described in U.S. Pat. No. 6,508,988 to van Dam et al., each of which is incorporated herein by reference in its entirety.

IV.C. Method of Incorporating a PFPE-based Microfluidic Device into an Integrated Fluid Flow System.

[0194] In some embodiments, the method of performing a chemical reaction or flowing a material within a PFPE-based microfluidic device comprises incorporating the microfluidic device into an integrated fluid flow system. Referring now to FIG. **10**, a system for carrying out a method of flowing a material in a microfluidic device and/or a method of performing a chemical reaction in accordance with the presently disclosed subject matter is schematically depicted. The system itself is generally referred to at **1000**. System **1000** can comprise a central processing unit **1002**, one or more driving force actuators **1010**A, **1010**B, **1010**C, and **1010**D, a collector **1020**, and a detector **1030**. In some embodiments, detector **1030** is in fluid communication with the microfluidic device (shown in shadow). System microfluidic device **1000** of FIG. **8**, and these reference numerals of FIG. **8** are employed in FIG. **10**. Central processing unit (CPU) **1002** can be, for example, a general purpose personal computer with a related monitor, keyboard or other desired user interface. Driving force actuators **1010**A, **1010**B, **1010**C, and **1010**D can be any suitable driving force actuator as would be apparent to one of ordinary skill in the art upon review of the presently disclosed subject matter. For example, driving force actuators **1010**A, **1010**B, **1010**C, and **1010**D can be pumps, electrodes, injectors, syringes, or other such devices that can be used to force a material through a microfluidic device. Representative driving forces themselves thus include capillary action, pump driven fluid flow, electrophoresis based fluid flow, pH gradient driven fluid flow, or other gradient driven fluid flow.

[0195] In the schematic of FIG. **10** driving force actuator **1010**D is shown as connected at outlet aperture **810**D, as will be described below, to demonstrate that at least a portion of the driving force can be provided at the end point of the desired flow of solution, reagent, and the like. Collector **1020** is also provided to show that a reaction product **1048**, as discussed below, can be collected at the end point of system flow. In some embodiments, collector **1020** comprises a fluid reservoir. In some embodiments, collector **1020** comprises a substrate. In some embodiments, collector **1020** comprises a detector. In some embodiments, collector **1020** comprises a subject in need of therapeutic treatment. For convenience, system flow is generally represented in FIG. **10** by directional arrows F**1**, F**2**, and F**3**.

[0196] Continuing with reference to FIG. **10**, in some embodiments a chemical reaction is performed in integrated flow system **1000**. In some embodiments, material **1040**, e.g, a chemical reagent, is introduced to microfluidic device **1000** through aperture **810**A, while a second material **1042**, e.g., a second chemical reagent, is introduced to microfluidic device **1000**, via inlet aperture **810**B. Driving force actuators **1010**A and **1010**B propel chemical reagents **1040** and **1042** to microfluidic channels **831** and **833**, respectively. Flow of chemical reagents **1040** and **1042** continues to fluid reservoirs **850**A and **850**B, where a reserve of reagents **1040** and **1042** is collected. Flow of chemical reagents **1040** and **1042** continues into microfluidic channels **832** and **834** to intersection point **860**A wherein initial contact between chemical reagents **1040** and **1042** occurs. Flow of chemical reagents **1040** and **1042** then continues to reaction chamber **870** where a chemical reaction between chemical reagents **1040** and **1042** proceeds.

[0197] Continuing with reference to FIG. **10**, reaction product **1044** flows to microscale channel **836** and to intersection point **860**B. Chemical reagent **1046** then reacts with reaction product **1044** beginning at intersection point **860**B through reaction chamber **838** and to fluid reservoir **850**C. A second reaction product **1048** is formed. Flow of the second reaction product **1048** continues through microscale channel **840** to aperture **810**D and finally into collector **1020**. Thus, it is noted that CPU **1002** actuates driving force actuator **1010**C such that chemical reagent **1046** is released at an appropriate time to contact reaction product **1044** at intersection point **860**B.

IV.D. Representative Applications of a PFPE-Based Microfluidic Device

[0198] In some embodiments, the presently disclosed subject matter discloses a method of screening a sample for a characteristic. In some embodiments, the presently disclosed subject matter discloses a method of dispensing a material. In some embodiments, the presently disclosed subject matter discloses a method of separating a material. Accordingly, one of ordinary skill in the art would recognize that the PFPE-based microfluidic device described herein can be applied to many applications, including, but not limited to, genome mapping, rapid separations, sensors, nanoscale reactions, ink-jet printing, drug delivery, Lab-on-a-Chip, in vitro diagnostics, injection nozzles, biological studies, high-throughput screening technologies, such as for use in drug discovery and materials science, diagnostic and therapeutic tools, research tools, and the biochemical monitoring of food and

natural resources, such as soil, water, and/or air samples collected with portable or stationary monitoring equipment.

IV.D.1. Method of Screening a Sample for a Characteristic

[0199] In some embodiments, the presently disclosed subject matter discloses a method of screening a sample for a characteristic, the method comprising:

[0200] (a) providing a microfluidic device comprising a patterned layer of a photocured perfluoropolyether, wherein the patterned layer of the photocured perfluoropolyether comprises a plurality of channels;

[0201] (b) providing a target material;

[0202] (c) disposing the sample in at least one of the plurality of channels;

[0203] (d) contacting the sample with the target material; and

[0204] (e) detecting an interaction between the sample and the target material, wherein the presence or the absence of the interaction is indicative of the characteristic of the sample.

[0205] Referring once again to FIG. **10**, at least one of materials **1040** and **1042** comprises a sample. In some embodiments, at least one of materials **1040** and **1042** comprises a target material. Thus, a "sample" generally refers to any material about which information relating to a characteristic is desired. Also, a "target material" can refer to any material which can be used to provide information relating to a characteristic of a sample based on an interaction between the target material and the sample. In some embodiments, for example, when sample **1040** contacts target material **1042** an interaction occurs. In some embodiments, the interaction produces a reaction product **1044**. In some embodiments, the interaction comprises a binding event. In some embodiments, the binding event comprises the interaction between, for example, an antibody and an antigen, a substrate and a ligand, or more particularly, a receptor and a ligand, or a catalyst and one or more chemical reagents. In some embodiments, the reaction product is detected by detector **1030**.

[0206] In some embodiments, the method comprises disposing the target material in at least one of the plurality of channels. Referring once again to FIG. **10**, in some embodiments, the target material comprises active material **880**. In some embodiments, the target material comprises a substrate, for example non-patterned layer NPL as shown in FIGS. **2**A-**2**D. In some embodiments, the substrate comprises a semiconductor material. Referring now more particularly to FIGS. **2**B-**2**D, in some embodiments, at least one of the plurality of channels of the microfluidic device is in fluid communication with the substrate, e.g., non-patterned layer NPL. In some embodiments, the target material is disposed on a substrate, e.g., non-patterned layer NPL. In some embodiments, at least one of the plurality of channels of the microfluidic device is in fluid communication with the target material disposed on the substrate.

[0207] In some embodiments, the method comprises disposing a plurality of samples in at least one of the plurality of channels. In some embodiments, the sample is selected from the group consisting of a therapeutic agent, a diagnostic agent, a research reagent, a catalyst, a metal ligand, a non-biological organic material, an inorganic material, a foodstuff, soil, water, and air. In some embodiments, the sample comprises one or more members of one or more libraries of chemical or biological compounds or components. In some embodiments, the sample comprises one or more of a nucleic acid template, a sequencing reagent, a primer, a primer extension product, a restriction enzyme, a PCR reagent, a PCR reaction product, or a combination thereof. In some embodi-

ments, the sample comprises one or more of an antibody, a cell receptor, an antigen, a receptor ligand, an enzyme, a substrate, an immunochemical, an immunoglobulin, a virus, a virus binding component, a protein, a cellular factor, a growth factor, an inhibitor, or a combination thereof.

[0208] In some embodiments, the target material comprises one or more of an antigen, antibody, an enzyme, a restriction enzyme, a dye, a fluorescent dye, a sequencing reagent, a PCR reagent, a primer, a receptor, a ligand, a chemical reagent, or a combination thereof.

[0209] In some embodiments, the interaction comprises a binding event. In some embodiments, the detecting of the interaction is performed by at least one or more of a spectrophotometer, a fluorometer, a photodiode, a photomultiplier tube, a microscope, a scintillation counter, a camera, a CCD camera, film, an optical detection system, a temperature sensor, a conductivity meter, a potentiometer, an amperometric meter, a pH meter, or a combination thereof.

[0210] Accordingly, after a review of the present disclosure, one of ordinary skill in the art would recognize that the presently disclosed PFPE-based microfluidic device can be used in various screening techniques, such as those described in U.S. Pat. Nos. 6,749,814 to Bergh et al., 6,737,026 to Bergh et al., 6,630,353 to Parce et al., 6,620,625 to Wolk et al., 6,558,944 to Parce et al., 6,547,941 to Kopf-Sill et al., 6,529,835 to Wada et al., 6,495,369 to Kercso et al., and 6,150,180 to Parce et al., each of which is incorporated by reference in its entirety. Further, after a review of the present disclosure, one of ordinary skill in the art would recognize that the presently disclosed PFPE-based microfluidic device can be used, for example, to detect DNA, proteins, or other molecules associated with a particular biochemical system, as described in U.S. Pat. No. 6,767,706 to Quake et al., which is incorporated herein by reference in its entirety.

IV.D.2. Method of Dispensing a Material

[0211] In some embodiments, the presently disclosed subject matter describes a method of dispensing a material, the method comprising:

[0212] (a) providing a microfluidic device comprising a patterned layer of a photocured perfluoropolyether, wherein the patterned layer of the photocured perfluoropolyether comprises a plurality of channels, and wherein at least one of the plurality of channels comprises an outlet aperture;

[0213] (b) providing at least one material;

[0214] (c) disposing at least one material in at least one of the plurality of channels; and

[0215] (d) dispensing at least one material through the outlet aperture.

[0216] Referring once again to FIG. **10**, in some embodiments, a material, e.g., material **1040**, second material **1042**, chemical reagent **1046**, reaction product **1044**, and/or reaction product **1048** flow through outlet aperture **810**D and are dispensed in or on collector **1020**.

[0217] In some embodiments, the material comprises a drug. In some embodiments, the method comprises metering a predetermined dosage of the drug. In some embodiments, the method comprises dispensing the predetermined dosage of the drug.

[0218] In some embodiments, the material comprises an ink composition. In some embodiments, the method comprises dispensing the ink composition on a substrate. In some embodiments, the dispensing of the ink composition on a substrate forms a printed image.

[0219] Accordingly, after a review of the present disclosure, one of ordinary skill in the art would recognize that the presently disclosed PFPE-based microfluidic device can be used for microfluidic printing as described in U.S. Pat. Nos. 6,334,676 to Kaszczuk et al., 6,128,022 to DeBoer et al., and 6,091,433 to Wen, each of which is incorporated herein by reference in its entirety.

IV.D.3 Method of Separating a Material

[0220] In some embodiments, the presently disclosed subject matter describes a method of separating a material, the method comprising:

[0221] (a) providing a microfluidic device comprising a patterned layer of a photocured perfluoropolyether, wherein the patterned layer of the photocured perfluoropolyether comprises a plurality of channels, and wherein at least one of the plurality of channels comprises a separation region;

[0222] (b) disposing a mixture comprising at least a first material and a second material in the microfluidic device;

[0223] (c) flowing the mixture into at least one of the plurality of channels comprising a separation region; and

[0224] (d) separating the first material from the second material in the separation region to form at least one separated material.

[0225] Referring once again to FIG. **10**, in some embodiments, at least one of material **1040** and second material **1042** comprise a mixture. For example, material **1040**, e.g., a mixture, flows through the microfluidic system to chamber **870**, which in some embodiments comprises a separation region. In some embodiments, the separation region comprises active material **880**, e.g., a chromatographic material. Material **1040**, e.g., a mixture, is separated in chamber **870**, e.g., a separation chamber, to form a third material **1044**, e.g., a separated material. In some embodiments, separated material **1044** is detected by detector **1030**.

[0226] In some embodiments, the separation region comprises a chromatographic material. In some embodiments, the chromatographic material is selected from the group consisting of a size-separation matrix, an affinity-separation matrix; and a gel-exclusion matrix, or a combination thereof.

[0227] In some embodiments, the first or second material comprises one or more members of one or more libraries of chemical or biological compounds or components. In some embodiments, the first or second material comprises one or more of a nucleic acid template, a sequencing reagent, a primer, a primer extension product, a restriction enzyme, a PCR reagent, a PCR reaction product, or a combination thereof. In some embodiments, the first or second material comprises one or more of an antibody, a cell receptor, an antigen, a receptor ligand, an enzyme, a substrate, an immunochemical, an immunoglobulin, a virus, a virus binding component, a protein, a cellular factor, a growth factor, an inhibitor, or a combination thereof.

[0228] In some embodiments, the method comprises detecting the separated material. In some embodiments, the detecting of the separated material is performed by at least one or more of a spectrophotometer, a fluorometer, a photodiode, a photomultiplier tube, a microscope, a scintillation counter, a camera, a CCD camera, film, an optical detection system, a temperature sensor, a conductivity meter, a potentiometer, an amperometric meter, a pH meter, or a combination thereof.

[0229] Accordingly, after a review of the present disclosure, one of ordinary skill in the art would recognize that the presently disclosed PFPE-based microfluidic device can be used to separate materials, as described in U.S. Pat. Nos. 6,752,922 to Huang et al., 6,274,089 to Chow et al., and 6,444,461 to Knapp et al., each of which is incorporated herein by reference in its entirety.

V. EXAMPLES

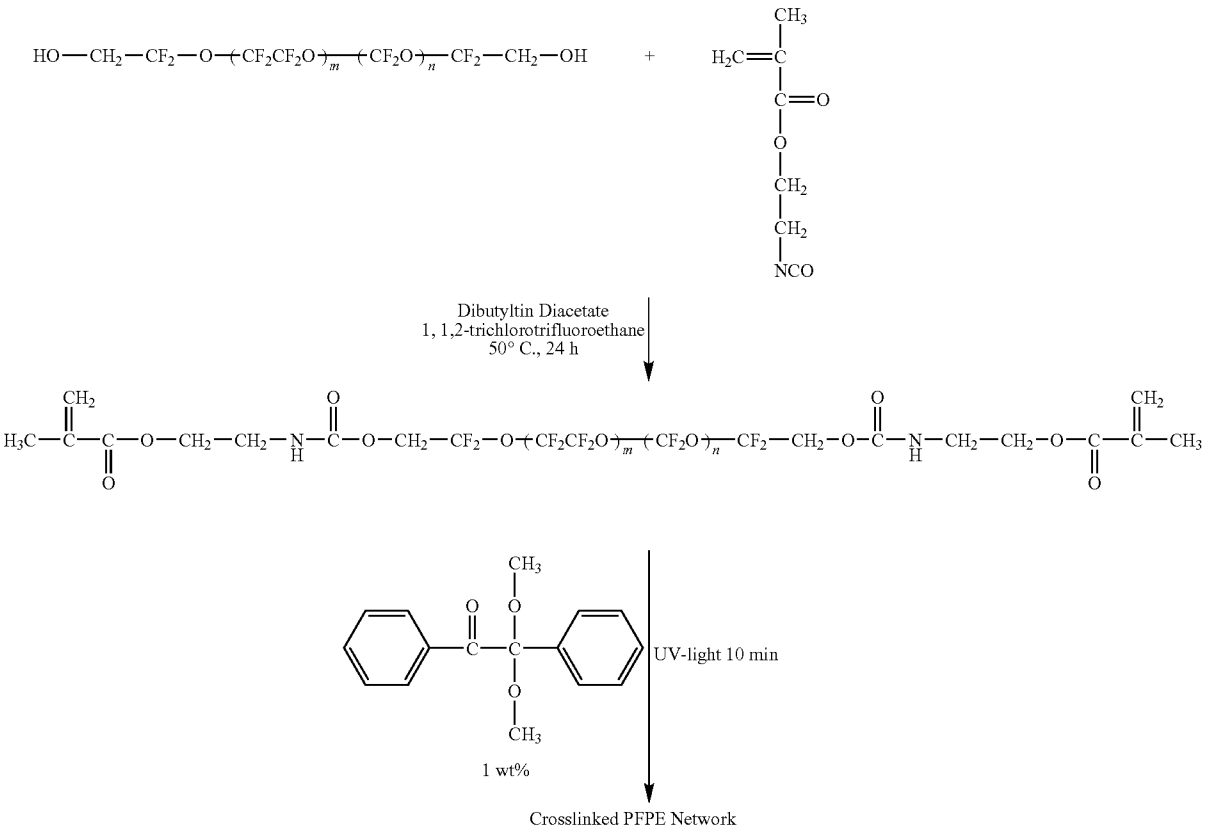
[0230] The following Examples have been included to illustrate modes of the presently disclosed subject matter. Certain aspects of the following Examples are described in terms of techniques and procedures found or contemplated to work well in the practice of the presently disclosed subject matter. In light of the present disclosure and the general level of skill in the art, those of skill can appreciate that the following Examples are intended to be exemplary only and that numerous changes, modifications, and alterations can be employed without departing from the scope of the presently disclosed subject matter.

Example 1

Synthesis of Photocured Functionalized PFPE Materials

[0231] A representative scheme for the synthesis and photocuring of a functionalized perfluoropolyether is provided in Scheme 1.

Scheme 1. Synthesis and Photocuring of Functionalized Perfluoropolyethers.



[0232] This method is based on a previously reported procedure. See Priola, A. et al., *Macromol. Chem. Phys.* 1997, 198, 1893-1907. The reaction involves the methacrylate functionalization of a commercially available PFPE diol ((M_n) 3800 g/mol) with isocyanatoethyl methacrylate. Subsequent photocuring of the material is accomplished through blending with 1 wt % of 2,2-dimethoxy-2-phenylacetophenone and exposure to UV radiation (λ=365 nm).

Example 2

Materials

[0233] Poly(tetrafluoroethylene oxide-co-difluoromethylene oxide)α,ω diol (ZDOL, Average M_n ca. 3,800 g/mol, 95% Aldrich Chemical Company, Milwaukee, Wis., United States of America), 2-Isocyanatoethyl methacrylate (EIM, 99% Aldrich), 2,2-Dimethoxy-2-phenyl acetophenone (DMPA, 99% Aldrich), Dibutyltin diacetate (DBTDA, 99% Aldrich), and 1,1,2-trichlorotrifluoroethane (Freon 113, 99% Aldrich) were used as received.

Example 3

Preparation of PFPE Dimethacrylate (DMA)

[0234] In a typical synthesis, ZDOL (5.7227 g, 1.5 mmol) was added to a dry 50 mL round bottom flask and purged with argon for 15 minutes. EIM (0.43 mL, 3.0 mmol) was then

added via syringe along with Freon 113 (2 mL), and DBTDA (50 μL). The solution was immersed in an oil bath and allowed to stir at 50° C. for 24 h. The solution was then passed through a chromatographic column (alumina, Freon 113, 2 cm×5 cm). Evaporation of the solvent yielded a clear, colorless, viscous oil, which was further purified by passage through a 0.22-μm polyethersulfone filter. ^{1}H-NMR (ppm): 2.1, (3H); 3.7, q (2H); 4.4, t (2H); 4.7, t (2H); 5.3, m (1H); 5.8, s (1H); 6.3, s (1H).

Example 4

Photocuring of PFPE DMA

[0235] In a typical cure, 1 wt % of DMPA (0.05 g, 2.0 mmol) was added to PFPE DMA (5 g, 1.2 mmol) along with 2 mL Freon 113 until a clear solution was formed. After removal of the solvent, the cloudy viscous oil was passed through a 0.22-μm polyethersulfone filter to remove any DMPA that did not disperse into the PFPE DMA. The filtered PFPE DMA was then irradiated with a UV source (Electrolite UV curing chamber model no. 81432-ELC-500, Danbury, Conn., United States of America, λ=365 nm) while under a nitrogen purge for 10 min, yielding a clear, slightly yellow, rubbery material.

Example 5

Device Fabrication with PFPE DMA

[0236] In a typical fabrication, PFPE DMA containing photoinitiator (as described in Example 4) was spin coated to a thickness of 20 μm (800 rpm) onto a Si wafer containing the desired photoresist pattern. This wafer was then placed into the UV curing chamber and irradiated for 6 s. Separately, a thick layer (~5 mm) of the material was produced by pouring the PFPE DMA containing photoinitiator into a mold surrounding the Si wafer containing the desired photoresist pattern. This wafer was irradiated with UV light for 1 min. Following this step, the thick layer was removed and inlet holes were carefully punched in specific areas of the device. The thick layer was then carefully placed on top of the thin layer such that the patterns in the two layers were precisely aligned, and then the entire device was irradiated for 10 min. Once complete, the entire device was peeled from the wafer with both layers adhered together. These curing times were determined to be the optimal exposure times to achieve a good balance between structure failure and proper adhesion of the two layers.

Example 6

Swelling Experiments

[0237] Swelling experiments were performed by soaking fully cured PFPE DMA and fully cured Sylgard® 184 (Dow Corning, Midland, Mich., United States of America) in dichloromethane. The % Swelling was determined using the following equation:

$$\% \text{ Swelling} = 100\% * (Wt - W_0)/W_0$$

where Wt is the weight of the material immediately after soaking in dichloromethane for time t and being patted dry with a paper tissue, and W_0 is the original weight of the material.

Example 7

Rheometry

[0238] Viscosities of the two elastomer precursors (PFPE DMA and Sylgard® 184) were measured on a TA Instruments AR2000 Rheometer (New Castle, Del., United States of America). Measurements were taken on approximately 3-5 mL of material. Measurements on the Sylgard® **184** precursors were taken immediately after mixing the two components. The shear rate for Sylgard® 184 was varied from 0.03 s^{-1} to 0.70 s^{-1} and resulted in a constant viscosity at each shear rate. The shear rate for PFPE DMA was varied from 0.28 s^{-1} to 34.74 s^{-1} and also resulted in a constant viscosity regardless of the shear rate. Viscosities were obtained by taking an average of the viscosity values over all measured shear rates on a logarithmic plot. The raw data for these experiments are shown in FIG. **11**.

Example 8

Dynamic Mechanical Analysis (DMA)

[0239] Modulus measurements were taken on a PerkinElmer DMA 7e Dynamic Mechanical Analyzer (Boston, Mass., United States of America). Samples were cut into 4-mm×8-mm×0.5-mm (width×length×thickness) rectangles. The initial static force on each of the two samples was 5 mN and the load was increased at rate of 500 mN/min until the sample ruptured or it reached 6400 mN. The tensile moduli were obtained from the initial slope (up to approximately 20% strain) of the stress/strain curves.

Example 9

Dynamic Mechanical Thermal Analysis

[0240] Thermal transitions of the two elastomers were obtained on a Seiko DMS 210 Dynamic Mechanical Thermal Analyzer (Seiko Instruments, Inc., Chiba, Japan). Samples were cut into 4-mm×20-mm×0.5-mm (width×length×thickness) rectangles. The following settings were used: Lamp=10, Min Tension/Compression force=10.000 g, Tension/Compression correction=1.2; Force amplitude=100. The temperature sweep ranged from −140° C. to 50° C. Tg's were obtained from the corresponding temperature at the maxima in a plot of E" (loss modulus) vs. temperature.

Example 10

Contact Angle Measurements

[0241] Static contact angles were measured using a KSV Instruments CAM 200 Optical Contact Angle Meter (KSV Instruments, Ltd., Helsinki, Finland). Droplets were placed on each of the fully cured elastomers using a 250-μL screw-top syringe.

Example 11

Results

[0242] To measure solvent resistance, tests using classical swelling measurements were performed on both the cross-linked PFPE DMA and Sylgard® 184, a PDMS. Rubinstein, M., et al., *Polymer Physics; Oxford University Press: New York,* 2003; p 398. Sample weight was compared before and after immersion in dichloromethane for several hours. The data show that after 94 h the PDMS network had swelled to 109% by weight, while the PFPE network showed negligible swelling (<3%).

[0243] The PDMS and PFPE precursor materials and the fully cured networks have similar processing and mechanical properties. Rheology experiments showed the viscosity of the uncured PFPE DMA at 25° C. to be 0.36 Pa·s, which is

significantly lower than that of 3.74 Pa·s for the uncured Sylgard®184. Because both materials are viscous oils at room temperature, however, standard PDMS device fabrication methods also could be used with the PFPE materials.

[0244] Said another way, the PFPE materials of the presently disclosed subject matter exhibit low viscosities and are pourable. These properties distinguish PFPE materials from other fluoroelastomers, such as Kalrez® (DuPont Dow Elastomers, L.L.C., Wilmington, Del., United States of America) and Viton® (DuPont Dow Elastomers, L.L.C., Wilmington, Del., United States of America), which have high viscosities. For example, the viscosity of Viton® is 7800 Pa·s at 160° C. Further, Kalrez® and Viton® are each cured thermally only.

[0245] Dynamic mechanical thermal analysis (DMTA) was performed on the fully cured materials. Both the PFPE and PDMS networks exhibited low temperature transitions (−112° C. and −128° C., respectively) as evidenced by maxima in the loss modulus E" (see FIG. **12**). This transition accounts for the similar elastic behavior of the two crosslinked materials at room temperature. Stress strain analysis shows that the tensile modulus of the fully cured PFPE-based elastomer is 3.9 MPa, which similar to that measured for fully cured Sylgard® 184 (2.4 MPa). Static contact angle measurements were made on both the elastomers.

[0246] As provided in Table IV, the PFPE DMA elastomer showed a higher contact angle than Sylgard® 184 for water and methanol. Toluene and dichloromethane instantly swelled Sylgard® 184 on contact, which prevented measurements to be taken. Contact angle values for these solvents were obtained for the PFPE DMA material, however, as no swelling occurred.

TABLE IV

	Static Contact Angles (deg)[a]			
Elastomer	Water	Methanol	Toluene	Dichloromethane
PFPE DMA	107	35	40	43
Sylgard ® 184	101	22	—	—

[a]A (—) indicates that the solvent swelled the material and no accurate measurement could be taken.

[0247] In some embodiments, device fabrication was accomplished according to the procedure illustrated in FIG. **13**. This procedure uses partial curing techniques to adhere the two layers without compromising feature sizes. Unger, M. A., et al., *Science* 2000, 288, 113-116. The PFPE DMA material was spin-coated and molded using procedures designed for Sylgard® 184.

[0248] To compare the solvent compatibility of devices made from the two materials, a dyed solution containing dichloromethane, acetonitrile, and methanol was introduced into a PFPE channel and a PDMS channel by capillary action (see FIG. **14**). The PFPE channels showed no evidence of swelling as the solution traveled easily through the channel. A pronounced reverse meniscus was observed, indicating good wetting behavior. In contrast, no solution entered the PDMS device because the channel was plugged shut when it made contact with the droplet. As a control, a dyed methanol solution was easily introduced in the PDMS channel in the same manner. Actuation of the valves was accomplished by introducing pressurized air (~25 psi) to small holes that were punched through the thick layer at the beginning of the channels. When the solution was present in the channel, valve actuation was observed (see FIG. **15**).

[0249] It will be understood that various details of the presently disclosed subject matter can be changed without departing from the scope of the presently disclosed subject matter. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation.

What is claimed is:

1. An apparatus having a microscale feature, comprising:
a first component defining a pattern, wherein the first component comprises an elastomeric material that is substantially resistant to swelling when in communication with substantially any organic solvent.

2. The apparatus of claim **1**, wherein the elastomeric material comprises a perfluoropolyether.

3. The apparatus of claim **1**, wherein the pattern comprises a recess.

4. The apparatus of claim **3**, further comprising a plurality of recesses defined in the first component.

5. The apparatus of claim **3**, wherein the recess includes a dimension less than about 1000 micrometers.

6. The apparatus of claim **3**, wherein the recess includes a dimension less than about 500 micrometers.

7. The apparatus of claim **3**, wherein the recess includes a dimension less than about 250 micrometers.

8. The apparatus of claim **3**, wherein the recess includes a dimension less than about 240 micrometers.

9. The apparatus of claim **3**, wherein the recess includes a dimension less than about 230 micrometers.

10. The apparatus of claim **3**, wherein the recess includes a dimension less than about 220 micrometers.

11. The apparatus of claim **3**, wherein the recess includes a dimension less than about 210 micrometers.

12. The apparatus of claim **3**, wherein the recess includes a dimension less than about 200 micrometers.

13. The apparatus of claim **3**, wherein the recess includes a dimension less than about 190 micrometers.

14. The apparatus of claim **3**, wherein the recess includes a dimension less than about 180 micrometers.

15. The apparatus of claim **3**, wherein the recess includes a dimension less than about 170 micrometers.

16. The apparatus of claim **3**, wherein the recess includes a dimension less than about 160 micrometers.

17. The apparatus of claim **3**, wherein the recess includes a dimension less than about 150 micrometers.

18. The apparatus of claim **3**, wherein the recess includes a dimension less than about 140 micrometers.

19. The apparatus of claim **3**, wherein the recess includes a dimension less than about 130 micrometers.

20. The apparatus of claim **3**, wherein the recess includes a dimension less than about 120 micrometers.

21. The apparatus of claim **3**, wherein the recess includes a dimension less than about 110 micrometers.

22. The apparatus of claim **3**, wherein the recess includes a dimension less than about 100 micrometers.

23. The apparatus of claim **3**, wherein the recess includes a dimension less than about 90 micrometers.

24. The apparatus of claim **3**, wherein the recess includes a dimension less than about 80 micrometers.

25. The apparatus of claim **3**, wherein the recess includes a dimension less than about 75 micrometers.

26. The apparatus of claim **3**, wherein the recess includes a dimension less than about 70 micrometers.

27. The apparatus of claim **3**, wherein the recess includes a dimension less than about 60 micrometers.

28. The apparatus of claim **3**, wherein the recess includes a dimension less than about 50 micrometers.

29. The apparatus of claim **3**, wherein the recess includes a dimension less than about 40 micrometers.

30. The apparatus of claim **3**, wherein the recess includes a dimension less than about 30 micrometers.

31. The apparatus of claim **3**, wherein the recess includes a dimension less than about 25 micrometers.

32. The apparatus of claim **3**, wherein the recess includes a dimension less than about 22.5 micrometers.

33. The apparatus of claim **3**, wherein the recess includes a dimension less than about 20 micrometers.

34. The apparatus of claim **3**, wherein the recess includes a dimension less than about 17.5 micrometers.

35. The apparatus of claim **3**, wherein the recess includes a dimension less than about 15 micrometers.

36. The apparatus of claim **3**, wherein the recess includes a dimension less than about 12.5 micrometers.

37. The apparatus of claim **3**, wherein the recess includes a dimension less than about 10 micrometers.

38. The apparatus of claim **3**, wherein the recess includes a dimension less than about 7.5 micrometers.

39. The apparatus of claim **3**, wherein the recess includes a dimension less than about 5 micrometers.

40. The apparatus of claim **3**, wherein the recess includes a dimension less than about 4 micrometers.

41. The apparatus of claim **3**, wherein the recess includes a dimension less than about 3 micrometers.

42. The apparatus of claim **3**, wherein the recess includes a dimension less than about 2 micrometers.

43. The apparatus of claim **3**, wherein the recess includes a dimension less than about 1 micrometer.

44. The apparatus of claim **3**, wherein the recess includes a dimension less than about 0.5 micrometer.

45. The apparatus of claim **3**, wherein the recess includes a dimension less than about 0.2 micrometer.

46. The apparatus of claim **3**, wherein the recess includes a dimension less than about 0.1 micrometer.

47. The apparatus of claim **3**, wherein the recess includes a dimension less than about 0.05 micrometer.

48. The apparatus of claim **3**, wherein the recess includes a dimension less than about 0.02 micrometer.

49. The apparatus of claim **3**, wherein the recess includes a dimension of about 0.01 micrometer.

50. The apparatus of claim **3**, wherein the recess includes a width-to-depth ratio of between about 0.1:1 to about 100:1.

51. The apparatus of claim **3**, wherein the recess includes a width-to-depth ratio of between about 1:1 to about 50:1.

52. The apparatus of claim **3**, wherein the recess includes a width-to-depth ratio of between about 2:1 to about 20:1.

53. The apparatus of claim **3**, wherein the recess includes a width-to-depth ratio of between about 3:1 to about 15:1.

54. The apparatus of claim **3**, wherein the recess includes a width-to-depth ratio of about 10:1.

55. The apparatus of claim **3**, wherein the recess includes a substantially rectangular predetermined shape.

56. The apparatus of claim **3**, wherein the recess includes a substantially trapezoidal predetermined shape.

57. The apparatus of claim **3**, wherein the recess includes a substantially circular predetermined shape.

58. The apparatus of claim **3**, wherein the recess includes a substantially ellipsoidal predetermined shape.

59. The apparatus of claim **3**, wherein the recess includes a substantially parabolic predetermined shape.

60. The apparatus of claim **3**, wherein the recess includes a substantially hyperparabolic predetermined shape.

61. The apparatus of claim **3**, wherein the recess includes a substantially polygonal predetermined shape.

62. An apparatus having a microscale feature, comprising:

a first component defining a pattern, wherein the first component comprises a perfluoropolyether.

63. The apparatus of claim **62**, wherein the pattern includes a plurality of microscale reservoirs.

64. The apparatus of claim **63**, wherein each microscale reservoir of the plurality of microscale reservoirs has a dimension between about 0.01 micrometer and about 1000 micrometers.

65. The apparatus of claim **63**, wherein each microscale reservoir of the plurality of microscale reservoirs has a dimension between about 0.05 micrometer and about 1000 micrometers.

66. The apparatus of claim **63**, wherein each microscale reservoir of the plurality of microscale reservoirs has a dimension between about 1 micrometer and about 1000 micrometers.

67. The apparatus of claim **63**, wherein each microscale reservoir of the plurality of microscale reservoirs has a dimension between about 0.2 micrometer and about 250 micrometers.

68. The apparatus of claim **3**, wherein each microscale reservoir of the plurality of microscale reservoirs includes a width-to-depth ratio of between about 0.1:1 to about 100:1.

69. The apparatus of claim **3**, wherein each microscale reservoir of the plurality of microscale reservoirs includes a width-to-depth ratio of between about 1:1 to about 50:1.

70. The apparatus of claim **3**, wherein each microscale reservoir of the plurality of microscale reservoirs includes a width-to-depth ratio of between about 2:1 to about 20:1.

71. The apparatus of claim **3**, wherein each microscale reservoir of the plurality of microscale reservoirs includes a width-to-depth ratio of between about 3:1 to about 15:1.

72. The apparatus of claim **3**, wherein each microscale reservoir of the plurality of microscale reservoirs includes a width-to-depth ratio of about 10:1.

73. An apparatus having a microscale feature, comprising:

a first component defining a pattern, wherein the first component comprises a perfluoropolyether, and wherein the pattern includes a recess having a dimension less than about 1000 micrometers.

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