US007217396B2

(12) United States Patent
Liu et al.

(10) **Patent No.: US 7,217,396 B2**

(45) **Date of Patent: May 15, 2007**

(54) **MICROFABRICATED MICRO FLUID CHANNELS**

(75) Inventors: **Chang Liu**, Champaign, IL (US); **Kee Ryu**, Urbana, IL (US); **David Bullen**, Urbana, IL (US)

(73) Assignee: **The Board of Trustees of the University of Illinois**, Urbana, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 203 days.

(21) Appl. No.: **10/429,333**

(22) Filed: **May 5, 2003**

(65) **Prior Publication Data**

US 2004/0223886 A1 Nov. 11, 2004

(51) **Int. Cl.**
B01L 3/02 (2006.01)

(52) **U.S. Cl.** **422/100**; 422/101; 422/102

(58) **Field of Classification Search** 422/100–102
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,284,113	B1	9/2001	Bjornson et al.	
6,409,900	B1	6/2002	Parce et al.	
6,429,025	B1	8/2002	Parce et al.	
6,555,389	B1 *	4/2003	Ullman et al.	436/514
2001/0020588	A1 *	9/2001	Adourian et al.	204/451
2001/0036674	A1	11/2001	Indermuhle et al.	
2002/0025279	A1 *	2/2002	Weigl et al.	422/100
2002/0123153	A1	9/2002	Moon et al.	
2003/0017077	A1 *	1/2003	Hahn et al.	422/81
2003/0026740	A1 *	2/2003	Staats	422/102
2003/0082080	A1 *	5/2003	Zimmermann et al.	422/100
2004/0018116	A1 *	1/2004	Desmond et al.	422/58

OTHER PUBLICATIONS

Zou, et al., "A mould-and-transfer technology for fabricating scanning probe microscopy probes," Oct. 15, 2003, Institute of Physics Publishing, Journal of Micromechanics and Microenginneering, 14, 204-211.*

Piner, et al., "'Dip-Pen" Nanolithography,' Jan. 29, 1999, Science, 283, 661-663.*

Baldock et al., "Microfabricated Devices for Chemical and Biochemical Analysis Systems," Department of Instrumentation and Analytical Science, Manchester, United Kingdom, 1 page.

Kirk-Othmer, "Integrated Circuits," Encyclopedia of Chemical Technology, 1995, pp. 677-709, vol. 14.

Niklaus et al., "Void-Free Full Wafer Adhesive Bonding," Department of Signals, Sensors and Systems, Royal Institute of Technology, Stockholm, Sweden, 6 pages.

Van Zant, "Semiconductor Devices and Integrated Circuit Formation," Microchip Fabrication: A Practical Guide to Semiconductor Processing, 2000, pp. 491-527, Chapter 16.

International Search Report dated Nov. 30, 2005 for corresponding PCT application No. PCT/US04/13974.

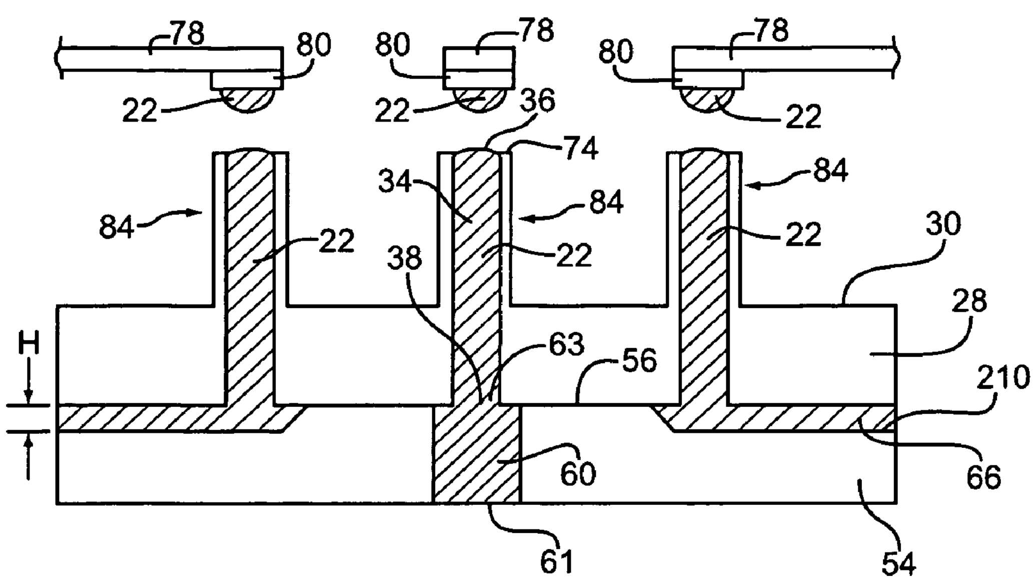
* cited by examiner

Primary Examiner—Jill Warden
Assistant Examiner—Jan Ludlow
(74) *Attorney, Agent, or Firm*—Evan Law Group LLC

(57) **ABSTRACT**

A fluid delivery system including a first substrate having a micro-channel and a well both formed through the first substrate. The fluid delivery system also includes a second substrate and a delivery channel. The second substrate is on the first substrate and the delivery channel is formed between the first and second substrates. The delivery channel provides fluid communication between the micro-channel and the well.

17 Claims, 4 Drawing Sheets



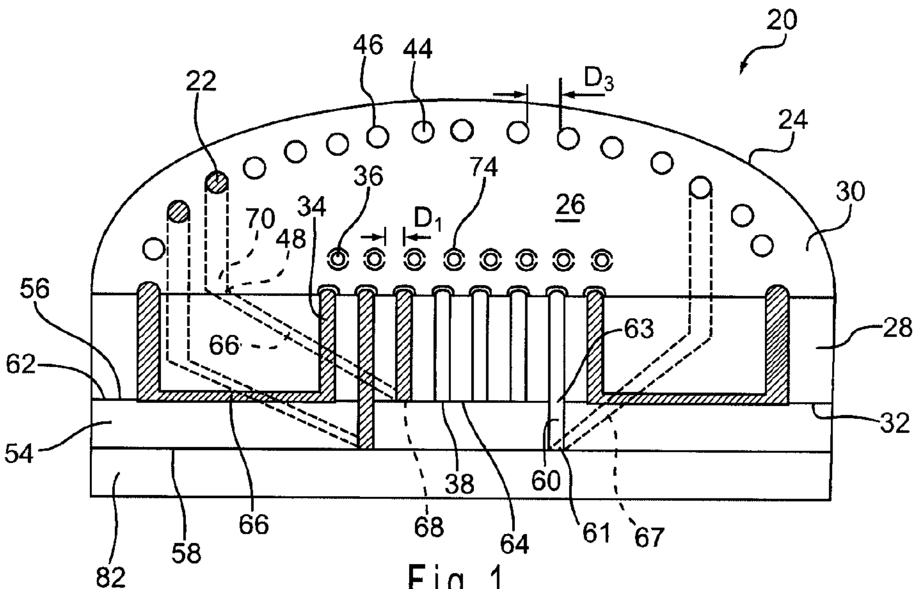

20
46
44
D3
22
24
30
36
74
26
70
34
D1
48
56
63
28
66
62
32
54
38
60
66
68
64
61
67
82
58

Fig. 1

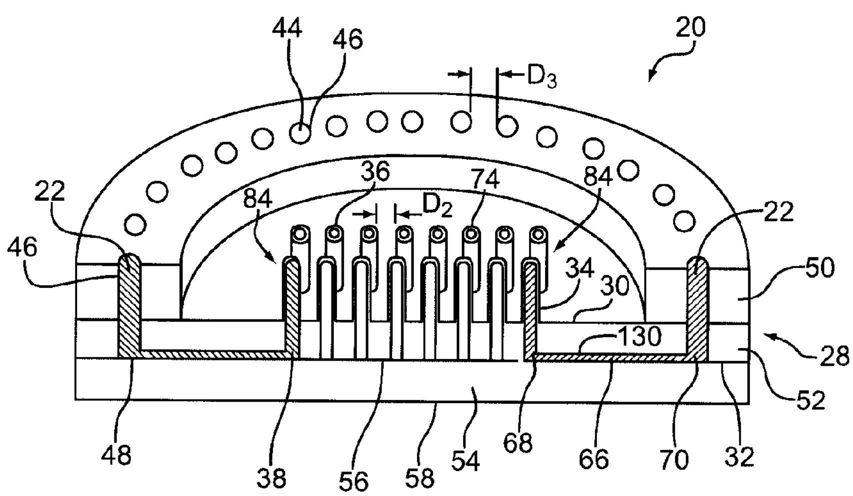

20
44
46
D3
36
74
84
D2
84
22
22
46
34
50
30
130
28
52
48
38
56
58
54
68
66
70
32

Fig. 2

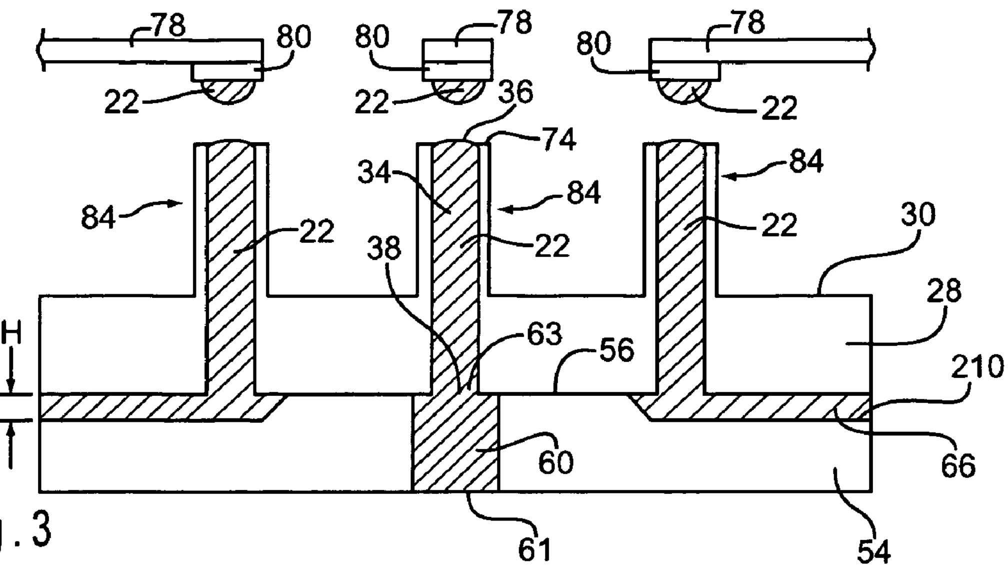


Fig.3

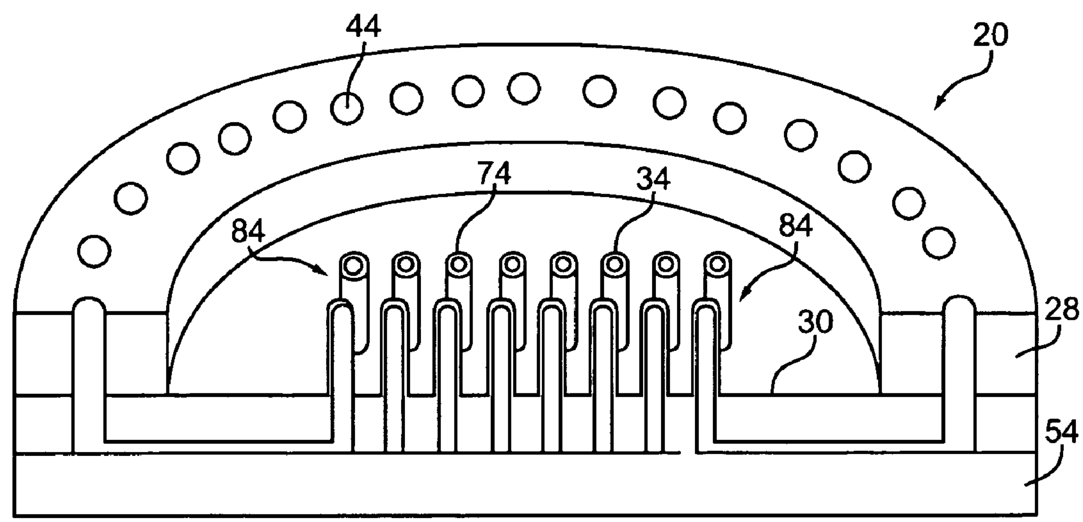


Fig.4

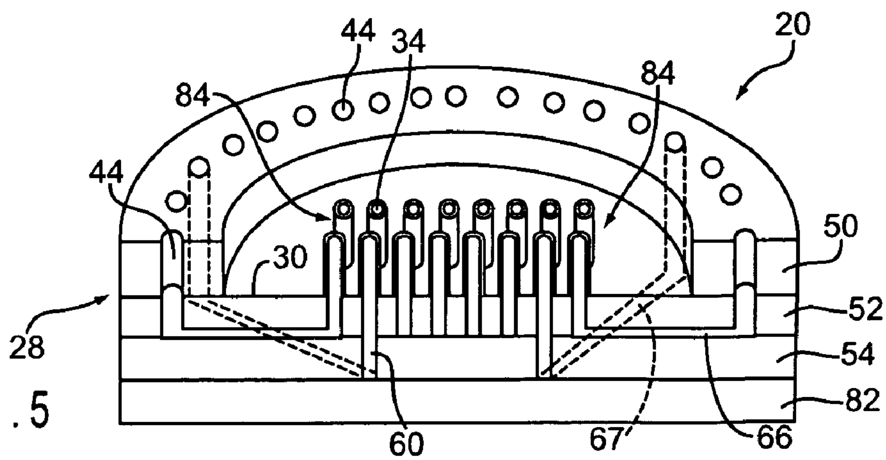


Fig.5

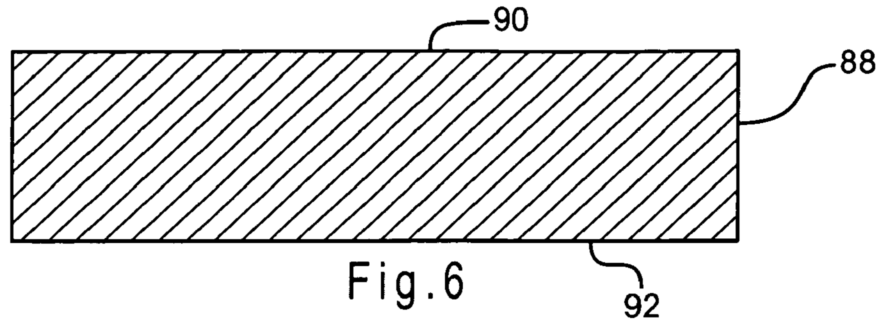


Fig.6

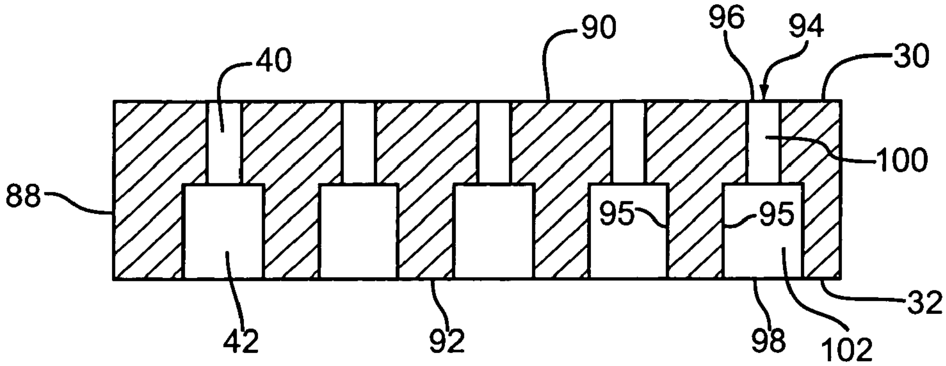


Fig.7

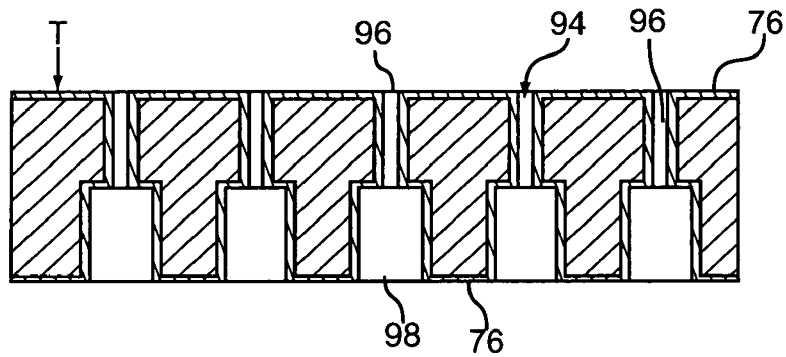


Fig.8

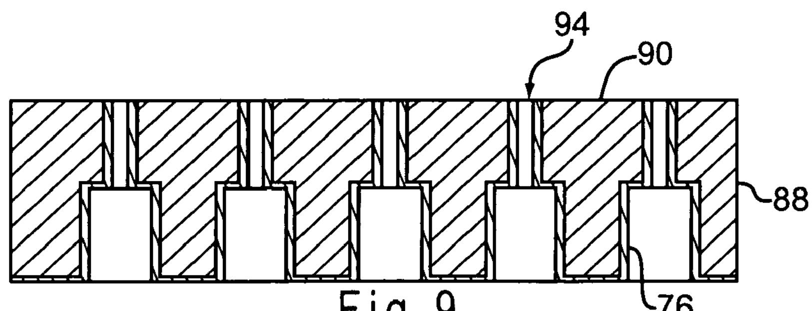


Fig.9

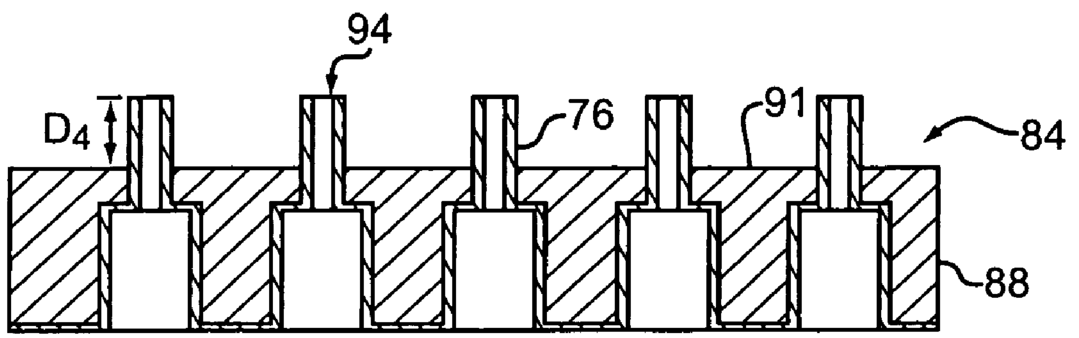


Fig.10

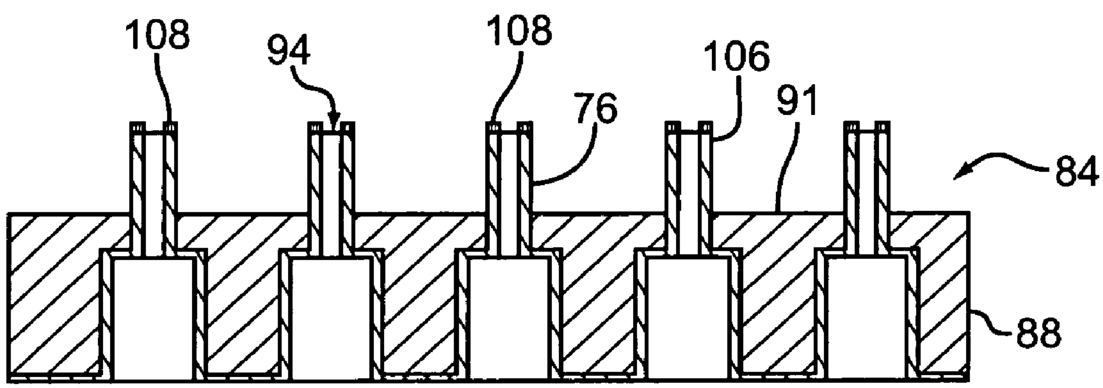


Fig.11

MICROFABRICATED MICRO FLUID CHANNELS

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under Contract Number DAAD19-00-1-0414 awarded by Army Research Office (ARO), and Contract Number F49620-01-1-0401 awarded by Air Force Office of Scientific Research (AFOSR). The Government may have has certain rights in the invention.

BACKGROUND

This invention relates generally to array chemical transfer devices, and in particular, to a fluid delivery system having an array of micro-channels in fluid connection with an array of wells.

In nanolithography, such as dip pen lithography (DPN) or other types of arrayed chemical transfer methods, it is desirable to provide inks, chemical or biological fluids, to a plurality of probes simultaneously. An arrayed fluid dispensing system with matching spatial configuration to the probe array would allow efficient inking of such an array of probes. Neighboring probes with very small distances between them can receive distinct inks. The probes can then be used to create high density arrays of biochemical substances, such as DNA or protein arrays.

BRIEF SUMMARY

According to one aspect of the present invention, a method for fabricating a fluid delivery system is provided. The method includes attaching a first substrate and a second substrate to form a delivery channel between the first substrate and the second substrate. The delivery channel provides fluid communication between a first micro-channel and a first well. The first micro-channel and the first well are both in the first substrate.

According to another aspect of the present invention, a fluid delivery system is provided. The fluid delivery system includes a first substrate having a micro-channel and a well both formed through the first substrate. The fluid delivery system also includes a second substrate and a delivery channel. The second substrate is on the first substrate, and the delivery channel is formed between the first and second substrates. The delivery channel provides fluid communication between the micro-channel and the well.

According to another aspect of the present invention, a method for forming a micro-pipette is provided. The method includes etching a top surface of a substrate to remove a portion of the substrate. The substrate has a micro-channel formed through the first substrate, where the top surface is opposed to a bottom surface. The top surface, the bottom surface, and the micro-channel are coated with a support material.

According to another aspect of the present invention, an apparatus for transferring fluid is provided. The apparatus includes a substrate having a top surface opposed to a bottom surface and a layer of support material. The substrate and the layer of support material form a micro-channel. The micro-channel opens at the bottom surface of the substrate and extends above the top surface of the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a cross-sectional view of a fluid delivery system containing multiple substrates, in accordance with one preferred embodiment of the invention;

FIG. **2** illustrates a cross-sectional view of a fluid delivery system containing multiple substrates, in accordance with one preferred embodiment of the invention;

FIG. **3**. illustrates an enlarged cross-sectional view of a portion of a fluid delivery system containing multiple substrates, in accordance with one preferred embodiment of the invention;

FIG. **4**. illustrates a cross-sectional view of a fluid delivery system containing multiple substrates, in accordance with one preferred embodiment of the invention;

FIG. **5**. illustrates a cross-sectional view of a fluid delivery system containing multiple substrates, in accordance with one preferred embodiment of the invention; and

FIGS. **6**–**11** illustrate, in cross-section, process steps for the fabrication of a micro-pipette structure for use in a fluid delivery system in accordance with one preferred embodiment of the invention.

It should be appreciated that for simplicity and clarity of illustration, elements shown in the Figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements are exaggerated relative to each other for clarity. Further, where considered appropriate, reference numerals have been repeated among the Figures to indicate corresponding elements.

DETAILED DESCRIPTION

The present invention includes micro fluid channels. The micro fluid channels are formed by etching partially or completely through a substrate. The micro fluid channels may protrude from the substrate to form micro-pipettes, which may be in the form of an array. The channels may be part of a fluid delivery system, including one or more additional substrates, with channels between the substrates connecting the micro fluid channel to wells having a larger size, allowing for various fluids to easily be delivered to the micro fluid channel. These micro fluid channels may then be used to ink a probe or array of probes, to spot surfaces. This will allow for patterning, with the various fluids, to form, for example high density arrays of biochemical substances.

A "micro fluid channel" or "micro-channel" means a channel having a cross-sectional area of at most 10,000 square microns, more preferably at most 2500 square microns, most preferably at most 100 square microns.

Shown in FIG. **1**, in cross-section, is a fluid delivery system **20** which includes a first substrate **28** overlying a second substrate **54**. Preferably, the first and second substrate **28**, **54** comprise a single crystal silicon substrate; however, first and second substrate **28**, **54** may comprise other materials. Preferably, the substrates **28**, **54** each have a thickness of 1000 to 200 microns, such as 300 to 500 microns. Preferably, the first and second substrates **28**, **54** have top surfaces **30**, **56** which are previously processed and cleaned to remove debris and native oxides.

First substrate **28** has a top surface **30** opposed to a bottom surface **32**. First substrate **28** also has an outer edge **24** surrounding an inside surface **26**, as illustrated in FIG. **1**. In one embodiment, the first substrate **28** is formed from a single substrate, as illustrated in FIGS. **1** and **4**, while in another embodiment, the first substrate **28** is formed from multiple substrates, such as an upper substrate **50** and a lower substrate **52**, and then bonded together, as illustrated in FIGS. **2** and **5**.

Upper and lower substrates **50**, **52** may be bonded in one of many ways, such as spin on bonding using photoresist or an adhesive polymer for adhesive bonding, which may be patterned (see for example "VOID-FREE FULL WAFER ADHESIVE BONDING" F. Niklaus, et al.); or high-temperature bonding, for example by heating the substrates together at about 1100° C. Alignment may be achieved using an alignment mark, or using features present on the substrates.

A micro-channel **34** is formed through the first substrate **28** from the top surface **30** to the bottom surface **32**. Preferably, the micro-channel **34** is formed by etching all the way through the first substrate **28** from the top surface **30** to the bottom surface **32**; however other means for forming the micro-channel **34** may be used, such as drilling. Preferably, the micro-channel **34** is formed using anisotropic etching. In one embodiment, the micro-channel **34** is formed by etching through the top surface **30** to form a first channel **40** and then etching through the bottom surface **32** to form a second channel **42**, wherein the first and second channels **40**, **42** are in fluid communication, as illustrated in FIG. **7**. Preferably, the cross-sectional area of the first channel **40** is less than the cross-sectional area of the second channel **42**. More preferably, the ratio of the cross-sectional area of the first channel **40** to the cross-sectional area of the second channel **42** is between 1 to 1 and 1 to 10.

The micro-channel **34** has an inlet **38** for receiving fluid **22** from a delivery channel **66** and an outlet **36** for delivering fluid **22**, preferably, to a probe **78**, as illustrated in FIG. **3**. In one embodiment, the outlet **36** has a cross-sectional area that is generally circular in shape. Preferably, the outlet **36** has a cross sectional area that is at most 10,000 square microns, more preferably at most 2,500 square microns, and most preferably at most 100 square microns. In one embodiment, the outlet **36** has a cross sectional area that is between ten and 10,000 square microns. Preferably, the inlet **38** has a cross-sectional area that is larger than the cross-sectional area of the outlet **36**. The cross-sectional areas and shapes of the inlet **38** and the outlet **36** may be freely chosen, using patterning techniques, such as those used to pattern semiconductor substrates.

Preferably, the first substrate **28** includes a hydrophobic surface **74** surrounding the outlet **36**, as illustrated in FIG. **1**. The hydrophobic surface **74** prevents fluid **22** from overflowing and unintentionally exiting the outlet **36**, and possibly causing cross-contamination between fluids **22**. The hydrophobic surface **74** can be formed in one of many ways, such as coating the outlet **36** of the micro-channel **34** with a hydrophobic material, for example a silane or thiol, such as 1-octadecanethiol (ODT), or a photoresist. Preferably, an array of micro-channels **34** is formed through the first substrate **28** from the top surface **30** to the bottom surface **32**, as illustrated in FIG. **1**. The distance D_1 between adjacent micro-channels **34** is preferably at most 1000 microns, more preferably at most 600 microns, most preferably at most 200 microns.

A well **44** is formed through the first substrate **28** from the top surface **30** to the bottom surface **32**. Preferably, the well **44** is formed by etching all the way through the first substrate **28** from the top surface **30** to the bottom surface **32**; however other means for forming the well **44** may be used, such as drilling. Preferably, the well **44** is formed using reactive ion etching. The well **44** has an inlet **46** for receiving fluid **22** from a fluid delivery device, such as a conventional pipette or pump. The well **44** also includes a well outlet **48** for delivering fluid **22** to the delivery channel **66**, as illustrated in FIG. **1**. In one embodiment, the well inlet **46** has a cross-sectional area that is generally circular in shape. Preferably, the well inlet **46** has a cross-sectional area that is greater than the cross-sectional area of the micro-channel outlet **36**. Forming the well inlet **46** with a cross-sectional area that is larger than the cross-sectional area of the micro-channel outlet **36** allows for fluids **22** to be easily injected into the well inlet **46**, and yet still be deliverable, through the smaller micro-channel outlet **36**, to a probe **78**. Preferably, the well inlet **46** has a cross sectional area that is between 1 and 20 square millimeters, more preferably between 3 and 12 square millimeters, and most preferably between 5 and 10 square millimeters. In one embodiment, the distance D_3 between adjacent wells **44** is greater than the distance D_1 between adjacent micro-channels **34** or the distance D_2 between adjacent micro-pipettes **84**, as illustrated in FIGS. **1** and **2**.

Preferably, the array of wells **44** is formed through the first substrate **28** from the top surface **30** to the bottom surface **32**, as illustrated in FIG. **1**. Preferably, the array of wells **44** is formed near the outer edge **24** of the first substrate **28**, while the array of micro-channels **34** is formed at the inside surface **26** of the first substrate **28**, as illustrated in FIG. **1**.

Second substrate **54** has a top surface **56** opposed to a bottom surface **58**. Second substrate **54** also has an outer edge **62** surrounding an inside surface **64**, as illustrated in FIG. **1**. Second substrate **54** is positioned so that the top surface **56** is on the bottom surface **32** of the first substrate **28**. In one embodiment, an extended channel **60** is formed through the second substrate **54** from the top surface **56** to the bottom surface **58**. Preferably, the extended channel **60** is formed by etching all the way through the second substrate **54** from the top surface **56** to the bottom surface **58**; however, other means for forming the extended channel **60** may be used, such as drilling. Preferably, the extended channel **60** is formed using reactive ion etching. The extended channel **60** has an inlet **61** for receiving fluid **22** from a secondary delivery channel **67** and an outlet **63** for delivering fluid **22** to the inlet **38** of the micro-channel **34**, as illustrated in FIGS. **1** and **3**. The secondary delivery channel **67** is formed between the second substrate **54** and a third substrate **82**, as illustrated in FIG. **1**. In one embodiment, the outlet **63** has a cross-sectional area that is generally circular in shape.

The delivery channel **66** is formed between the first and second substrates **28**, **54**, as illustrated in FIGS. **1** and **2**. Preferably, the height H of the delivery channel, as illustrated in FIG. **3**, is between one and twenty microns, and more preferably, at most ten microns. The delivery channel **66** may be formed in one of many ways. In one embodiment, the delivery channel **66** includes a groove **210** that is formed on the top surface **56** of the second substrate **54**. In one embodiment, the delivery channel **66** includes a groove **130** that is formed on the bottom surface **32** of the first substrate **28**. In one embodiment, the delivery channel **66** includes a first groove that is formed on the top surface **56** of the second substrate **54** and a second groove that is formed on the bottom surface **32** of the first substrate **28**. The first substrate **28** is aligned with the second substrate **54** **50** that the delivery channel **66** allows for fluid to travel between the micro-channel **34** and the well **44**. The delivery channel **66** includes an inlet **70** for receiving fluid and an outlet **68** for delivering fluid **22**. The delivery channel inlet **70** receives fluid **22** from the well outlet **48** of the well **44**, while the delivery channel outlet **68** delivers fluid **22** to the inlet **38** of the micro-channel **34**. The delivery channel inlet **70** is adjacent to the well outlet **48**, and the delivery channel outlet **68** is adjacent to the inlet **38**, as illustrated in FIG. **1**.

In one embodiment, the micro-channel **34** extends both above and below the top surface **30** of the first substrate **28**, as illustrated in FIGS. **2**–**5**. In this embodiment, the micro-channel **34** may be formed entirely from the first substrate **28**, a portion of the micro-channel **34** may be formed from the first substrate **28**, or the micro-channel **34** may be formed from a second material. The second material may be any material that can be formed or coated onto a surface, such as those used in semiconductor processing. Examples include oxides, such as silicon oxide and silicon oxynitride, nitrides such as silicon nitride and titanium nitride, metals such as tungsten and gold, and polymers. Preferably, the micro-channel **34** is formed from the second material, wherein the second material extends both above and below the top surface **30** of the first substrate **28**.

In one embodiment, a method for fabricating the fluid delivery system **20** is disclosed. Referring to FIG. **1** the fluid delivery system **20** is fabricated by attaching the first substrate **28** and the second substrate **54** to form the delivery channel **66**, wherein the delivery channel **66** provides fluid communication between the micro-channel **34** and the well **44**. Preferably, the first substrate **28** is aligned with the second substrate **54** so that the inlet **70** of the delivery channel **66** is adjacent the outlet **48** of the well **44**, while the outlet **68** of the delivery channel **66** is adjacent the inlet **38** of the micro-channel **34**. In this way, the micro-channel **34** is in fluid connection with the well **44**, and thus fluid **22** may travel from the inlet **46** of the well **44** through the well **44**, the delivery channel **66**, and the micro-channel **34**, only to exit at the outlet **36** of the micro-channel **34**. Preferably, either alignment marks or existing features on one or both of the first and second substrates **28**, **54** are used to align the first substrate **28** with the second substrate **54**.

Once the delivery channel **66** is formed, the fluid **22** is delivered to the well **44**. The fluid **22** travels down the well **44**, through the delivery channel **66**, and up the micro-channel **34** to the outlet **36**. Fluid **22** can be forced up into the micro-channel **34** by pumping the fluid **22** through the well **44** and the delivery channel **66**. Fluid **22** may be pumped through the well **44** and the delivery channel **66** using a variety of techniques, such as by creating a pressure differential between the inlet **46** and the outlet **36**, or simply by capillary action. Preferably, the fluid **22** is kept in the micro-channel **34** and prevented from unintentionally exiting the micro-channel **34** by creating a hydrophobic surface **74** adjacent the outlet **36** of the micro-channel **34**. Once the micro-channel **34** is filled with fluid **22**, the fluid **22** can then be transferred to a probe **78**, such as an SPM (Scanning Probe Microscopy) probe, and more specifically to the tip **80** of the probe **78**, as illustrated in FIG. **3**.

In one embodiment, a micro-pipette **84** forms the micro-channel **34**. Preferably, a portion of the micro-pipette **84** extends both above and below the top surface **30** of the first substrate **28**, as illustrated in FIG. **2**. Preferably, the fluid delivery system **20** includes an array of micro-pipettes **84**, as illustrated in FIGS. **2**–**5**, allowing for multiple fluids **22** to be dispensed from the array of micro-channels **34**.

In one embodiment, a method for fabricating the micro-pipette **84** is disclosed, as illustrated in FIGS. **6**–**11**. Referring to FIG. **6**, a substrate **88**, such as first substrate **28**, is provided. Preferably, the substrate **88** has a top surface **90** which is previously processed and cleaned to remove debris and native oxides. The top surface **90** is opposed to a bottom surface **92**. Preferably, the bottom surface **92** is also previously processed and cleaned to remove debris and native oxides.

Referring to FIG. **7**, a channel **94**, such as a micro-channel **34**, having a wall **95** is formed through the substrate **88** from the top surface **90** to the bottom surface **92**. Preferably, the channel **94** is formed by etching all the way through the substrate **88** from the top surface **90** to the bottom surface **92**; however, other means for forming the channel **94** may be used, such as drilling. Preferably, the channel **94** is formed using reactive ion etching. In one embodiment, the channel **94** is formed by etching through the top surface **92** to form a first channel **100** and then etching through the bottom surface **92** to form a second channel **102**, wherein the first and second channels **100**, **102** connect, as illustrated in FIG. **7**. The channel **94** has an inlet **98** for receiving fluid, such as fluid **22**, and an outlet **96** for delivering fluid to, for example, a probe, such as probe **78**. In one embodiment, the outlet **96** has a cross-sectional area that is generally circular in shape. In yet another embodiment, the inlet **98** has a cross-sectional area that is larger than the cross-sectional area of the outlet **96**. The cross-sectional areas and shapes of the inlet **98** and the outlet **96** may be freely chosen, using patterning techniques, such as those used to pattern semiconductor substrates.

After forming the channel **94**, the top surface **90**, the bottom surface **92**, and the wall **95** of the channel **94** are all coated with a layer **76** of support material, as illustrated in FIG. **8**. The support material may include any material that can be formed or coated onto a surface, such as those used in semiconductor processing. Examples include oxides, such as silicon oxide and silicon oxynitride, nitrides such as silicon nitride and titanium nitride, metals such as tungsten and gold, and polymers. The support material may be formed by chemical reaction with the substrate **88**, for example by oxidation, or by coating, for example with chemical vapor deposition or oblique angle physical vapor deposition. Preferably, the support material is different from the material contained in the substrate **88**. Multiple materials may also be used, and these may be applied with the first support material, or they may be applied after further processing steps. In one embodiment, the layer **76** is silicon dioxide which is formed by reacting the substrate **90**, preferably made of silicon, with oxygen.

After forming the layer **76**, a portion of the layer **76** is removed. Preferably, the layer **76** is removed from the top surface **90** to expose the top surface **90** of the substrate **88**. In one embodiment, the layer **76** is removed from the bottom surface **92** to expose the bottom surface **92** of the substrate **88**. Layer **76** may be removed in one of a number of ways, such as the use of chemical-mechanical polishing or etching. The channel **94** may be filled with a protectant, such as wax, to avoid damaging the channel **94** with a polishing agent. The protectant may be removed with a solvent, such as acetone.

Upon removing the layer **76**, the substrate **88** is then etched to remove a portion of either the top surface **90** or the bottom surface **92** of the substrate **88**, as illustrated in FIG. **10**. Preferably, the substrate **88** is etched to a depth D_4, as illustrated in FIG. **10**, of between 50 and 500 microns, and more preferably, a depth of at most 150 microns. Various types of etching may be used to remove a portion of the substrate **88**, such as wet etching with ethylene diamine pyrocatechol or potassium hydroxide, or dry etching. Preferably, the top surface **90** is etched to remove a portion of the substrate **88** and create an etched surface **91** which is closer to the bottom surface **92** than the original top surface **90**.

Preferably, upon etching the substrate **88**, a hydrophobic material is applied to the surface **106** surrounding the outlet **96** to create a hydrophobic surface **108**, as illustrated in FIG. **11**.

The individual processing steps used in accordance with the present invention are well known to those of ordinary skill in the art, and are also described in numerous publications and treatises, including: *Encyclopedia of Chemical Technology, Volume* 14 (Kirk-Othmer, 1995, pp. 677–709); *Semiconductor Device Fundamentals* by Robert F. Pierret (Addison-Wesley, 1996); *Silicon Processing for the VLSI Era* by Wolf (Lattice Press, 1986, 1990, 1995, vols 1–3, respectively); and *Microchip Fabrication: A Practical Guide to Semiconductor Processing* by Peter Van Zant (4^{th} Edition, McGraw-Hill, 2000). In order to etch through the substrate, techniques such as deep ion etching may be used (also known as the Bosch process).

The fluid delivery system may be used to form patterns using fluids on surfaces. For example, if the fluid is an ink, then a surface, such as paper, could be printed with the probes after they have received the ink, to form microprinting. Biological arrays may similarly be formed, for example by using fluids containing biological compounds, such as nucleotides (RNA, DNA, or PNA), proteins (enzymes, antibodies, etc.), lipids, carbohydrates, etc. to spot a substrate, such as glass, silicon, or polymers. Since each micro-channel may be supplied for a dedicated well, very complex arrays may be produced quickly.

Numerous additional variations in the presently preferred embodiments illustrated herein will be determined by one of ordinary skill in the art, and remain within the scope of the appended claims and their equivalents. For example, while the examples provided above relate to silicon-based semiconductor substrates, it is contemplated that alternative semiconductor materials can likewise be employed in accordance with the present invention, and that the semiconductor substrates may be undoped, P-doped, or N-doped. Suitable materials for the substrates include but are not limited to silicon, gallium arsenide, germanium, gallium nitride, aluminum phosphide, $Si_{1-x}Ge_x$ and $Al_xGa_{1-x}As$ alloys, wherein x is greater than or equal to zero and less than or equal to one, the like, and combinations thereof. Additional examples of materials for use in accordance with the present invention are set forth in *Semiconductor Device Fundamentals* by Robert F. Pierret (p. 4, Table 1.1, Addison-Wesley, 1996).

Although the invention has been described and illustrated with reference to specific illustrative embodiments thereof, it is not intended that the invention be limited to those illustrative embodiments. Those skilled in the art will recognize that variations and modifications can be made without departing from the spirit of the invention.

The invention claimed is:

1. A fluid delivery system, comprising:

a first substrate comprising:

a first micro-channel comprising a first micro-channel outlet,

a first well,

a second micro-channel comprising a second micro-channel outlet, and

a second well, each formed through the first substrate;

a second substrate on the first substrate;

a first delivery channel formed between the first and the second substrates, the first delivery channel establishing fluid communication between the first micro-channel and the first well; and

a second delivery channel establishing fluid communication between the second micro-channel and the second well; and

a scanning probe microscopy probe for receiving fluid from the micro-channels, wherein the probe is moveable to and from the micro-channel outlets,

where the first and second micro-channel outlets are separated by at most 1000 microns.

2. The system of claim **1**, wherein at least one of the delivery channels comprises a groove formed on a surface of the second substrate.

3. The system of claim **1**,

where each of the wells has an inlet for receiving fluid,

each of the micro-channels has an outlet for delivering fluid, and

a cross-sectional area of at least one of the well inlets is greater than a cross sectional area of at least one of the micro-channel outlets.

4. The system of claim **3**, wherein the cross sectional area of each of the well inlets is between one and twenty square millimeters, and the cross sectional area of each of the micro-channel outlets is between ten and 10,000 square microns.

5. The system of claim **3**, further comprising a hydrophobic surface surrounding each of the micro-channel outlets.

6. The system of claim **3**, wherein each of the micro-channel extends above and below a surface of the first substrate.

7. The system of claim **3**, wherein the first substrate comprises a plurality of substrates.

8. The system of claim **1**, further comprising a third substrate on the second substrate.

9. The system of claim **8**, the second substrate further comprising an extended channel establishing fluid communication between the second micro-channel and the second delivery channel, the extended channel formed through the second substrate; and

the second delivery channel formed between the second and the third substrates.

10. The system of claim **1**, where at least one delivery channel comprises a groove formed on a surface of the first substrate.

11. The system of claim **1**, where the first substrate has a thickness of at most 500 microns.

12. The system of claim **1**, where the first substrate is bonded to the second substrate by spin-on bonding or high temperature bonding.

13. The system of claim **1**, where the first and second micro-channels form a micro-pipette.

14. The system of claim **1**, where the micro-channels are formed by reactive ion etching.

15. The system of claim **14**, where the micro-channels are formed by a first etch on a top surface of the first substrate and a second etch on a bottom surface of the first substrate.

16. The system of claim **15**, where the first etch forms a first micro-channel width and the second etch forms a second micro-channel width, the first micro-channel width in fluid communication with the second micro-channel width.

17. The system of claim **1**, where the distance between the first and second wells is greater than the distance between the first and second micro-channels.

* * * * *