



US007402616B2

(12) **United States Patent**
Rodgers et al.

(10) **Patent No.:** **US 7,402,616 B2**
(45) **Date of Patent:** **Jul. 22, 2008**

(54) **FUSIBLE CONDUCTIVE INK FOR USE IN
MANUFACTURING MICROFLUIDIC
ANALYTICAL SYSTEMS**

(75) Inventors: **James Iain Rodgers**, Lochardil (GB);
Margaret Maclellennan, Culloden (GB);
James Moffat, Inverness (GB); **Alan
McNeillage**, Inverness (GB)

(73) Assignee: **Lifescan, Inc.**, Milpitas, CA (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 560 days.

(21) Appl. No.: **10/957,470**

(22) Filed: **Sep. 30, 2004**

(65) **Prior Publication Data**

US 2006/0074143 A1 Apr. 6, 2006

(51) **Int. Cl.**
C09D 11/00 (2006.01)
C09D 11/10 (2006.01)

(52) **U.S. Cl.** **523/160**; 523/161; 524/495;
524/496; 524/403; 524/423; 524/548; 524/400;
524/414

(58) **Field of Classification Search** 523/160,
523/161, 200, 205; 524/495, 496, 400, 414,
524/424, 404

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,047,283	A	9/1991	Leatherman et al.
5,707,502	A	1/1998	McCaffrey et al.
5,857,983	A	1/1999	Douglas et al.
5,888,390	A	3/1999	Craig
5,906,723	A	5/1999	Mathies et al.
6,110,576	A	8/2000	Decker et al.
6,176,962	B1	1/2001	Soane et al.
6,284,113	B1	9/2001	Bjornson et al.
6,322,736	B1	11/2001	Bao et al.
6,444,461	B1	9/2002	Knapp et al.
6,503,359	B2	1/2003	Virtanen
6,593,398	B2 *	7/2003	Breton et al. 523/160
6,599,408	B1 *	7/2003	Chan et al. 204/403.15
6,627,058	B1	9/2003	Chan

6,990,849	B2	1/2006	Bohm et al.
7,204,940	B2 *	4/2007	McDonald et al. 252/512
2002/0076597	A1 *	6/2002	Chang et al. 429/35
2002/0079219	A1	6/2002	Zhao
2002/0185183	A1	12/2002	O'Connor et al.
2002/0189946	A1	12/2002	Walnright et al.
2003/0010228	A1	1/2003	Lofink
2003/0029724	A1	2/2003	Derand et al.
2003/0136509	A1	7/2003	Virtanen
2003/0203504	A1	10/2003	Hefi
2003/0230488	A1	12/2003	Lawrence et al.
2004/0249253	A1	12/2004	Racchini et al.

FOREIGN PATENT DOCUMENTS

EP	0352925	B1	12/1994
EP	1367101	A1 *	12/2003
EP	1391242	A2	2/2004
WO	WO 97/30344	A1	8/1997
WO	WO 99/19717	A1	4/1999
WO	WO 00/62931	A1	10/2000
WO	WO 01/35088	A1	5/2001
WO	WO 01/41931	A3	6/2001
WO	WO 01/54810	A1	8/2001
WO	WO 02/024322	A3	3/2002
WO	WO 02/49507	A1	6/2002
WO	WO 03/045557	A2	6/2003

OTHER PUBLICATIONS

European Search Report, Munich, Germany, Nov. 28, 2005, re Euro-
pean Application 05256108.1.

Egloff, E. Ralph, "A Flexible Solution to Solderless Surface Mount",
Adhesives Age, pp. 16-20 (Dec. 1995).

* cited by examiner

Primary Examiner—Sanza L McClendon

(57) **ABSTRACT**

A fusible conductive ink for use in manufacturing microflu-
idic analytical systems includes micronised powder contain-
ing platinum and carbon, poly(bisphenol A-co-epichlorohy-
drin)-glycidyl end capped polymer, and a solvent. In addition,
the ratio of micronised powder to poly(bisphenol A-co-ep-
ichlorohydrin)-glycidyl end capped polymer is in the range of
3:1 to 1:3. The fusible conductive inks can be employed in the
manufacturing of microfluidic systems to form electrodes,
electrically conductive traces and/or electrically conductive
contact pads.

4 Claims, 8 Drawing Sheets

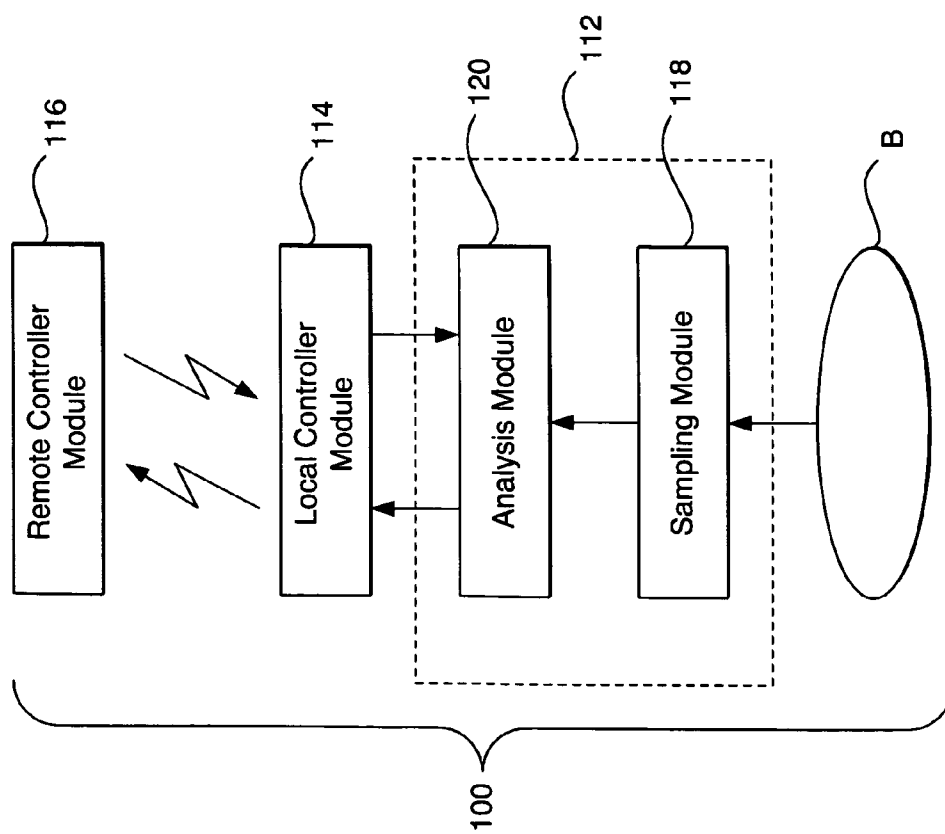


FIG. 1

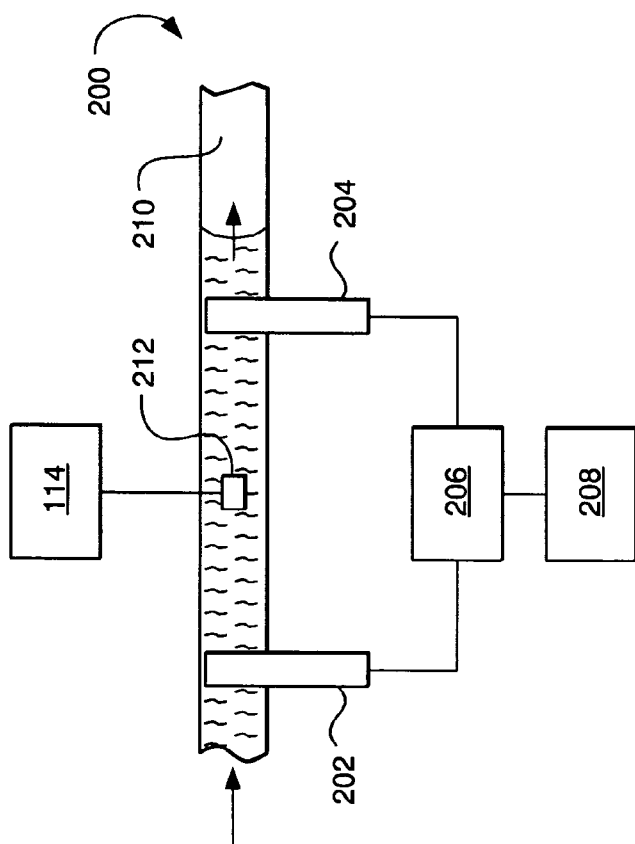


FIG. 2

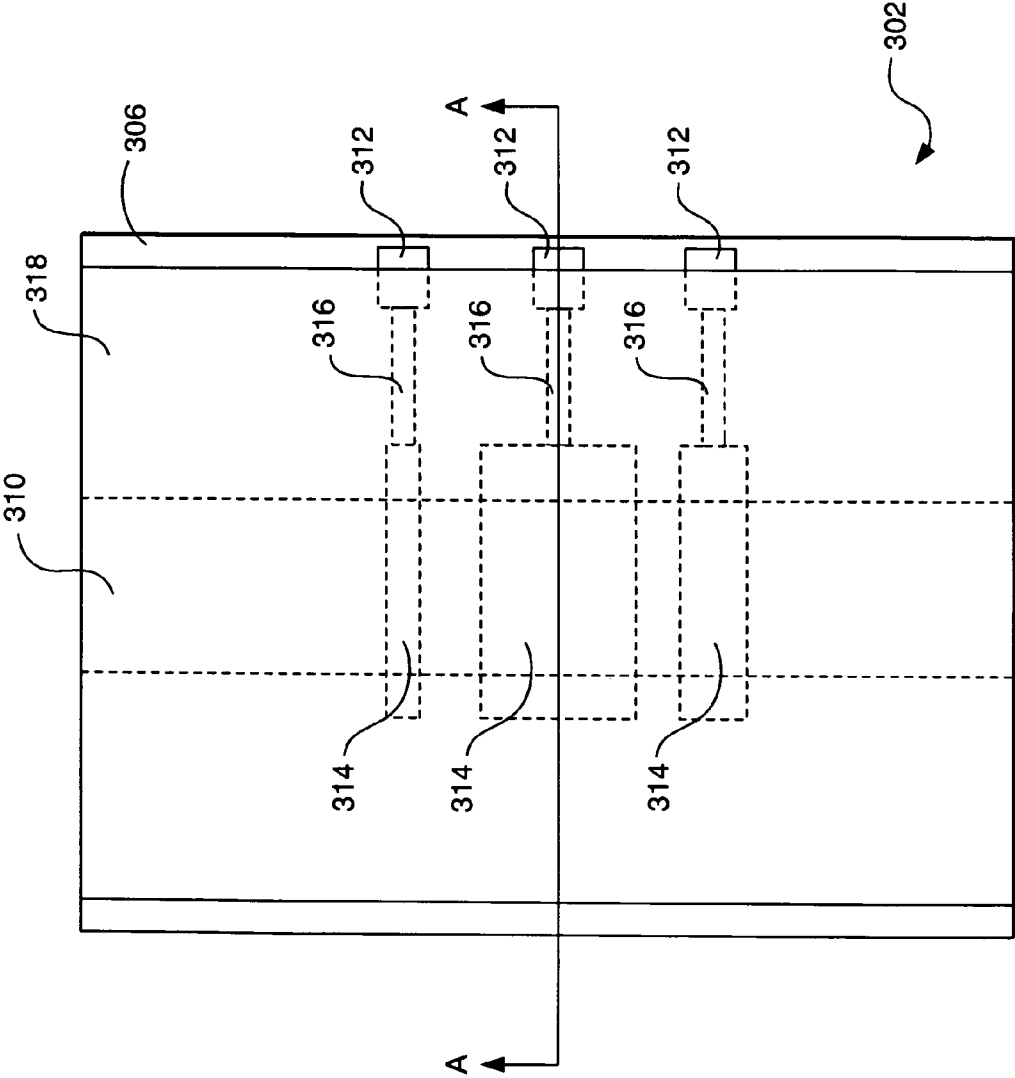


FIG. 3

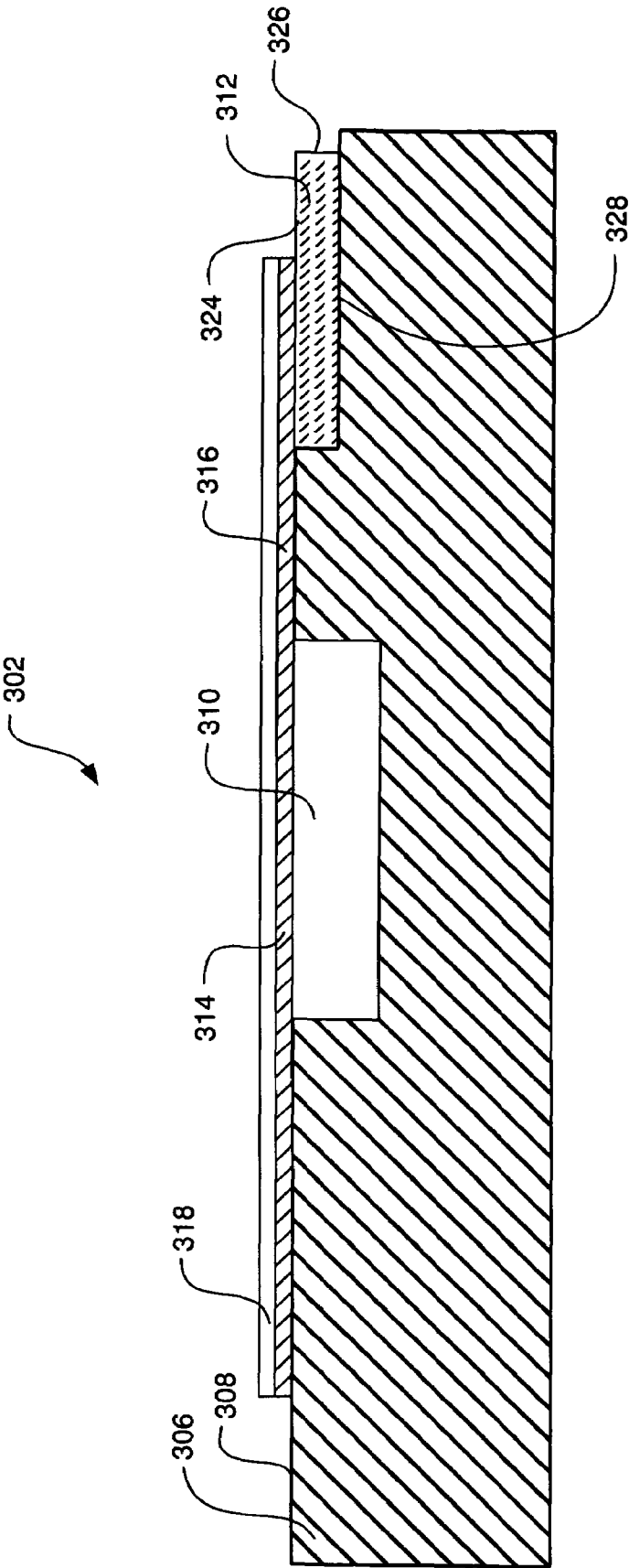


FIG. 4

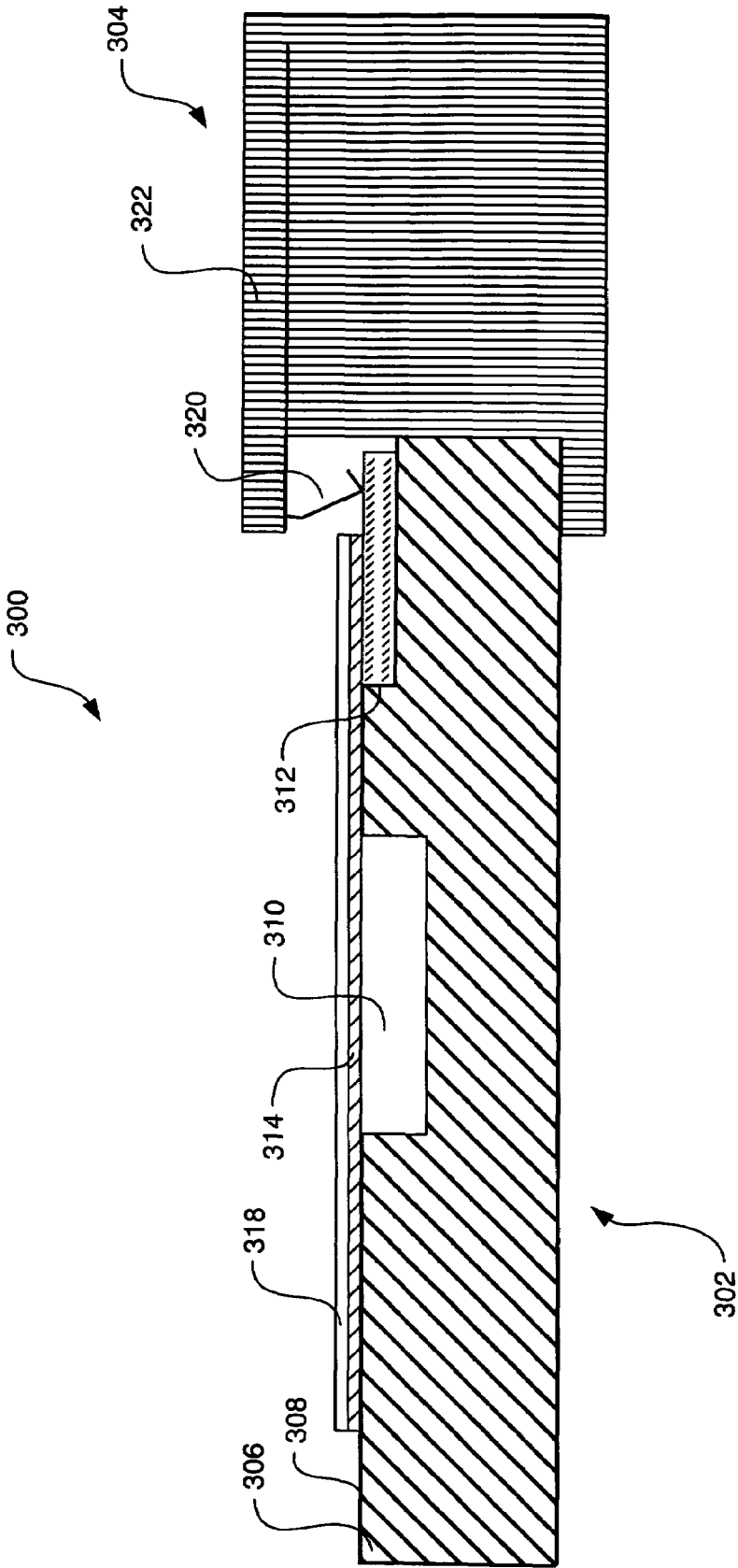


FIG. 5

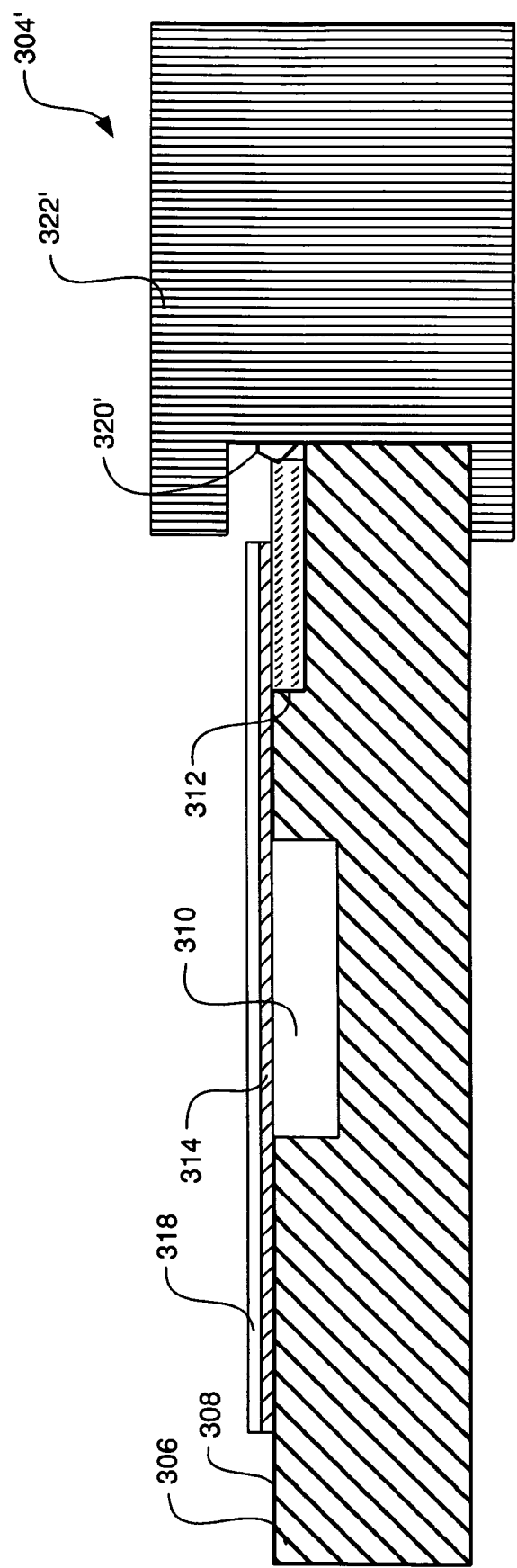


FIG. 6

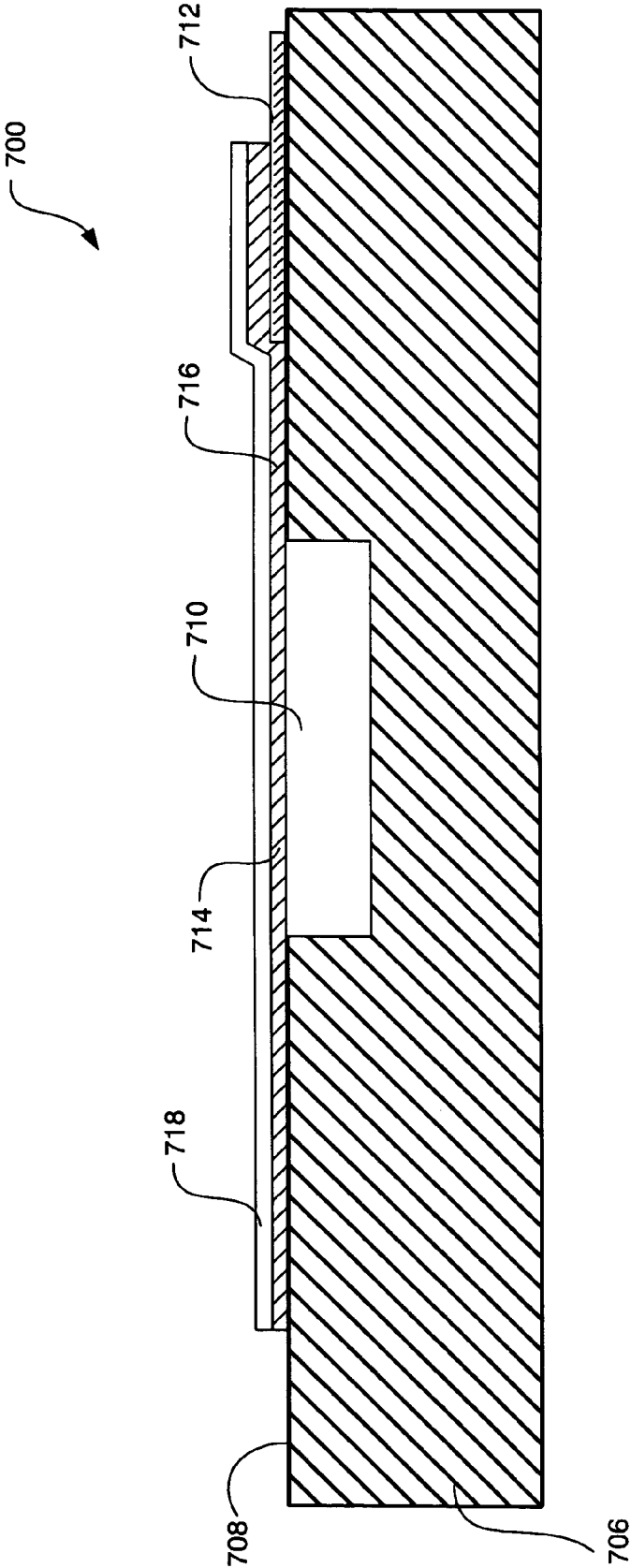


FIG. 7

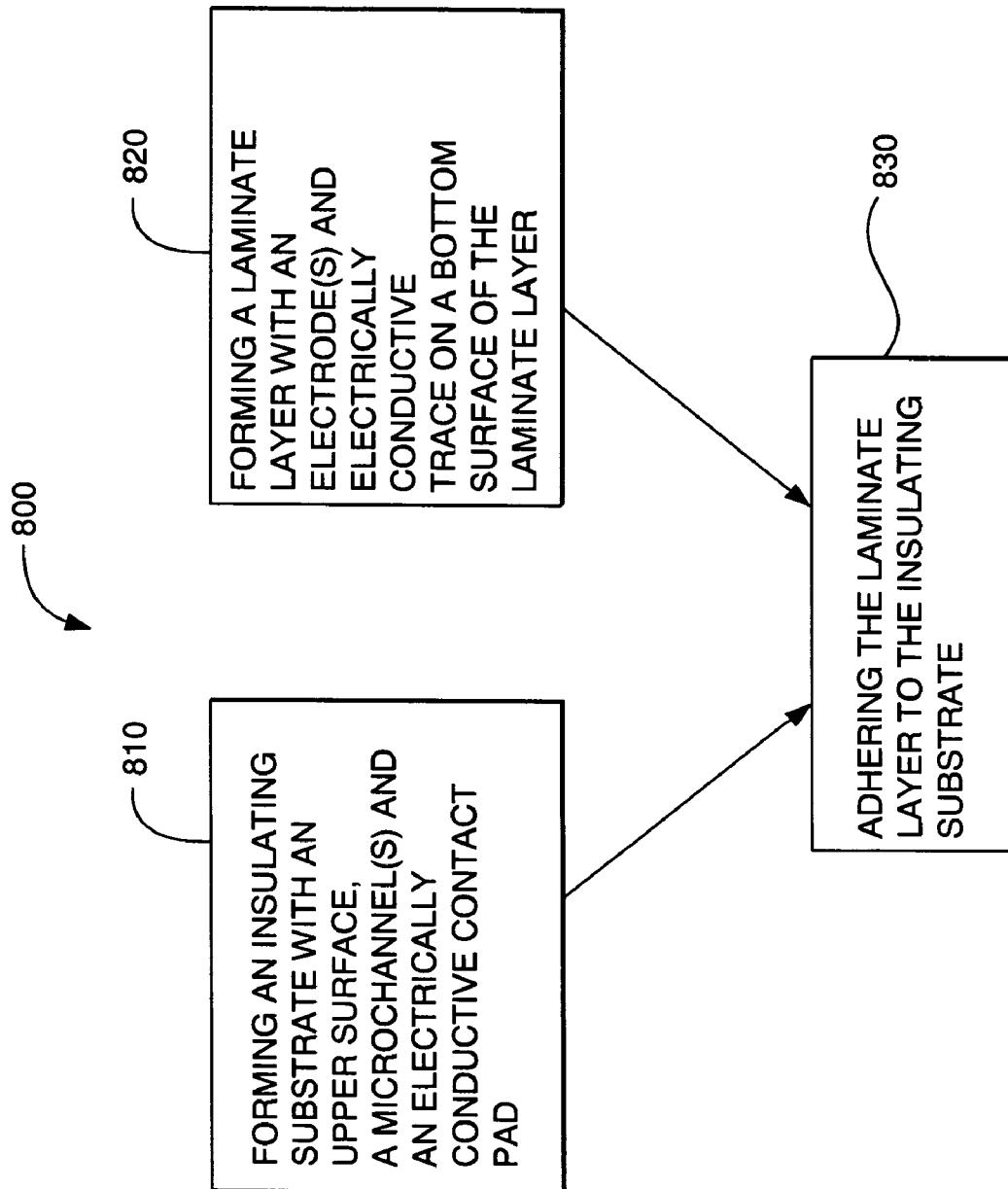


FIG. 8

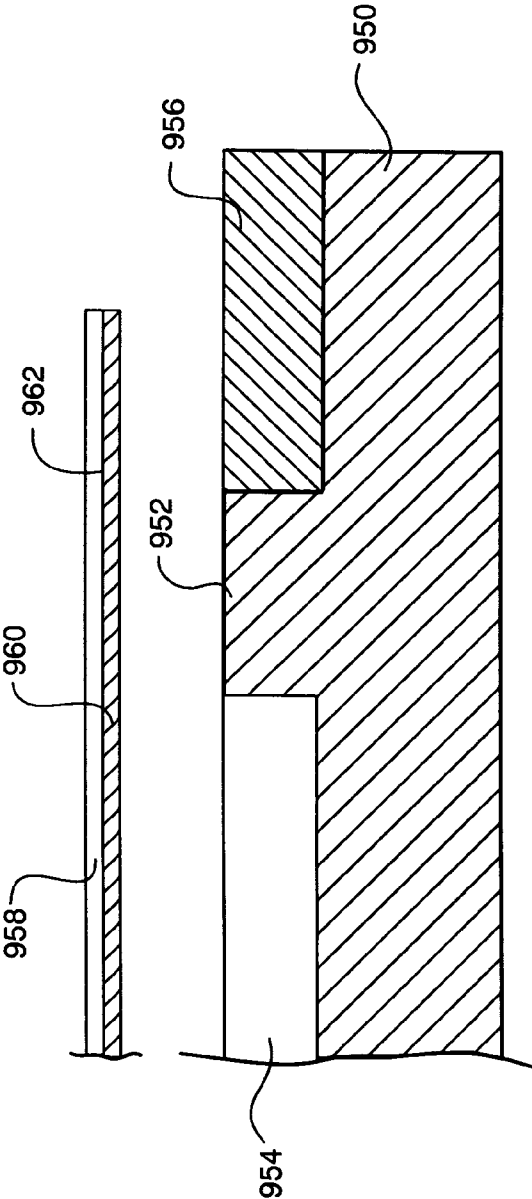


FIG. 9A

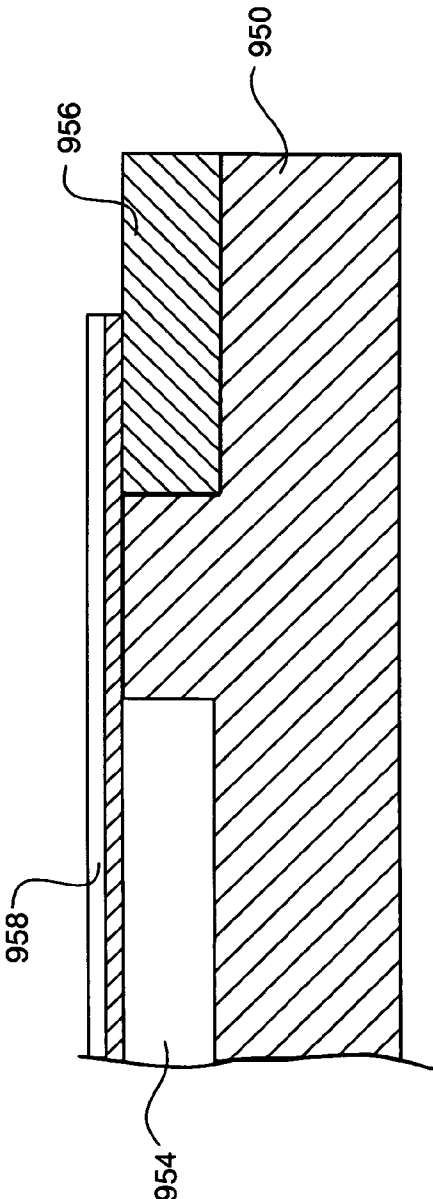


FIG. 9B

1

FUSIBLE CONDUCTIVE INK FOR USE IN MANUFACTURING MICROFLUIDIC ANALYTICAL SYSTEMS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates, in general, to analytical devices and, in particular, to materials for use in manufacturing microfluidic analytical systems.

2. Description of the Related Art

In analytical devices based on fluid samples (i.e., fluidic analytical devices), the requisite fluid samples should be controlled with a high degree of accuracy and precision in order to obtain reliable analytical results. Such control is especially warranted with respect to "microfluidic" analytical devices that employ fluid samples of small volume, for example, 10 nanoliters to 10 microliters. In such microfluidic analytical devices, the fluid samples are typically contained and transported in microchannels with dimensions on the order of, for example, 10 micrometers to 500 micrometers.

The control (e.g., transportation, position detection, flow rate determination and/or volume determination) of small volume fluid samples within microchannels can be essential in the success of a variety of analytical procedures including the determination of glucose concentration in interstitial fluid (ISF) samples. For example, obtaining reliable results may require knowledge of fluid sample position in order to insure that a fluid sample has arrived at a detection area before analysis is commenced.

The relatively small size of the fluid samples and microchannels in microfluidic analytical devices can, however, render such control problematic. For example, microchannels and surrounding structures (e.g., substrate(s) and electrode(s)) can suffer from a lack of unified structural integrity such that the microchannels are not adequately liquid and/or air tight.

In addition, microfluidic analytical devices often employ electrodes for a variety of purposes including analyte determination and fluid sample control (e.g., fluid sample position detection and fluid sample transportation). However, the electrodes employed in microfluidic analytical devices are relatively small and can be fragile in nature. As a consequence, the electrodes are susceptible to incomplete or weak electrical contact resulting in the creation of spurious and/or deleterious signals during operation.

Still needed in the field, therefore, are materials that can be employed in the manufacturing of an analytical devices that provide for a robust and secure electrical connection to electrodes within the analytical devices. Moreover, the materials should provide for any microchannels within the analytical device to be essentially liquid and/or air tight.

SUMMARY OF THE INVENTION

Fusible conductive inks according to embodiments of the present invention can be employed in the manufacturing of microfluidic systems such that a robust and secure electrical connection to electrodes within the microfluidic systems is provided. Furthermore, the fusible inks can also be employed to provide for microchannels within the microfluidic systems to be liquid and/or air tight.

Fusible conductive inks according to embodiments of the present invention include micronised powder containing platinum and carbon, poly(bisphenol A-co-epichlorohydrin)-glycidyl end capped polymer and a solvent. In addition, the

2

ratio of micronised powder to poly(bisphenol A-co-epichlorohydrin)-glycidyl end capped polymer is in the range of 3:1 to 1:3.

Fusible conductive inks according to the present invention can be employed in the manufacturing of microfluidic systems to form electrodes, electrically conductive traces and/or electrically conductive contact pads. In addition, since the fusible conductive inks are fusible, electrodes and electrically conductive traces formed from the inks can be fused with insulating substrates and laminate layers to aid in the formation of liquid and/or air tight microchannels. Furthermore, electrically conductive traces formed from the inks can be fused with electrically conductive contact pads to provide a secure and robust electrical connection between the electrically conductive contact pads and an electrode via the electrically conductive trace.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which principles of the invention are utilized, and the accompanying drawings, of which:

FIG. 1 is a simplified block diagram depicting a system for extracting a bodily fluid sample and monitoring an analyte therein with which embodiments of microfluidic analytical systems according to the present invention can be employed;

FIG. 2 is a simplified schematic diagram of a position electrode, microchannel, analyte sensor and meter configuration relevant to embodiments of microfluidic analytical systems according to the present invention;

FIG. 3 is a simplified top view (with dashed lines indicating hidden elements) of an analysis module of a microfluidic analytical system according to an exemplary embodiment of the present invention;

FIG. 4 is a simplified cross-sectional view of the analysis module of FIG. 3 taken along line A-A of FIG. 3;

FIG. 5 is a simplified cross-sectional view of the analysis module of FIG. 3 in electrical connection with an electrical device of the microfluidic analytical system;

FIG. 6 is a simplified cross-sectional view of the analysis module of FIG. 3 in electrical connection with a portion of an alternative electrical device;

FIG. 7 is a simplified cross-sectional view of another analysis module of a microfluidic analytical system according to the present invention;

FIG. 8 is a flow chart depicting an embodiment of a method in accordance with the present invention; and

FIGS. 9A and 9B are cross-sectional views illustrating steps in the method of FIG. 8.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

To be consistent throughout the present specification and for clear understanding of the present invention, the following definitions are hereby provided for terms used therein:

The term "fused" refers to the state of having been united by, or as if by, melting together.

The term "fusing" refers to the act of becoming united by, or as if by, melting together.

One skilled in the art will recognize that microfluidic analytical systems according to embodiments of the present invention can be employed, for example, as a subsystem in a variety of analytical devices. For example, embodiments of the present invention can be employed as an analysis module

3

of system **100** depicted in FIG. 1. System **100** is configured for extracting a bodily fluid sample (e.g., an ISF sample) and monitoring an analyte (e.g., glucose) therein. System **100** includes a disposable cartridge **112** (encompassed within the dashed box), a local controller module **114** and a remote controller module **116**.

In system **100**, disposable cartridge **112** includes a sampling module **118** for extracting the bodily fluid sample (namely, an ISF sample) from a body (B, for example, a user's skin layer) and an analysis module **120** for measuring an analyte (i.e., glucose) in the bodily fluid. Sampling module **118** can be any suitable sampling module known to those of skill in the art, while analysis module **120** can be a microfluidic analytical system according to embodiments of the present invention. Examples of suitable sampling modules are described in International Application PCT/GB01/05634 (published as WO 02/49507 A1 on Jun. 27, 2002) and U.S. patent application Ser. No. 10/653,023, both of which are hereby fully incorporated by reference. However, in system **100**, sampling module **118** is configured to be disposable since it is a component of disposable cartridge **112**.

FIG. 2 is a simplified schematic diagram of a position electrode, microchannel, analyte sensor and meter configuration **200** relevant to understanding microfluidic analytical systems according to the present invention. Configuration **200** includes first position electrode **202**, second position electrode **204**, electrical impedance meter **206**, timer **208**, microchannel **210** and analyte sensor **212**. In the configuration of FIG. 2, wavy lines depict a fluid sample (e.g., an ISF, blood, urine, plasma, serum, buffer or reagent fluid sample) within microchannel **210**.

Configuration **200** can be used to determine the position or flow rate of a fluid sample in microchannel **210**. In the configuration of FIG. 2, analyte sensor **212** is located in-between first position electrode **202** and second position electrode **204**. Electrical impedance meter **206** is adapted for measuring an electrical impedance between first position electrode **202** and second electrode **204**. Such a measurement can be accomplished by, for example, employing a voltage source to impose either a continuous or alternating voltage between first position electrode **202** and second position electrode **204** such that an impedance resulting from a conducting path formed by a fluid sample within microchannel **210** and between first position electrode **202** and second position electrode **204** can be measured, yielding a signal indicative of the presence of the fluid sample.

Furthermore, when electrical impedance meter **206** measures a change in impedance due to the presence of a fluid sample between the first and second position electrodes, a signal can be sent to timer **208** to mark the time at which liquid is first present between the first and second position electrodes. When the measured impedance indicates that the fluid sample has reached the second position electrode, another signal can be sent to timer **208**. The difference in time between when a fluid sample is first present between the first and second position electrodes and when the fluid sample reaches the second position electrode can be used to determine fluid sample flow rate (given knowledge of the volume of microchannel **210** between the first and second position electrodes). Furthermore, knowledge of fluid sample flow rate and/or fluid sample position can be used to determine total fluid sample volume. In addition, a signal denoting the point in time at which a fluid sample arrives at second position electrode **204** can also be sent to a local controller module (e.g., local controller module **114** of FIGS. 1 and 2) for operational use.

4

Further descriptions of microfluidic analytical devices with which microfluidic analytical systems according to embodiments of the present invention can be utilized are included in U.S. patent application Ser. No. 10/811,446, which is hereby fully incorporated by reference.

FIGS. 3, 4 and 5 are simplified depictions of a microfluidic analytical system **300** for monitoring an analyte in a fluid sample according to an exemplary embodiment of the present invention. Microfluidic analytical system **300** includes an analysis module **302** and an electrical device **304** (e.g., a meter and/or power supply).

Analysis module **302** includes an insulating substrate **306** with an upper surface **308**. Upper surface **308** has microchannel **310** therein. Analysis module **302** also includes three electrically conductive contact pads **312** disposed on the upper surface of insulating substrate **306**, three electrodes **314** disposed over microchannel **310**, electrically conductive traces **316** connected to each electrode **314** and to each electrically conductive contact pad **312** and a laminate layer **318**. Laminate layer **318** is disposed over electrodes **314**, electrically conductive traces **316**, and a portion of the upper surface **308** of insulating substrate **306**.

Electrical device **304** includes three spring contacts **320** (one of which is illustrated in FIG. 5) and a chassis **322** (see FIG. 5). Electrically conductive contact pads **312** of microfluidic analytical system **300** have accessible exposed surfaces **324** and **326** that provide for electrical connection to electrical device **304** via spring contacts **320**.

Insulating substrate **306** can be formed from any suitable material known to one skilled in the art. For example, insulating substrate **306** can be formed from an insulating polymer such as polystyrene, polycarbonate, polymethylmethacrylate, polyester and any combinations thereof. To enable electrical connection between the electrical device and the electrically conductive contact pads, it is particularly beneficial for the insulating substrate to be essentially non-compressible and have sufficient stiffness for insertion into the electrical device. Insulating substrate **306** can be of any suitable thickness with a typical thickness being approximately 2 mm.

Electrically conductive contact pads **312** can be formed from any suitable electrically conductive material known to one skilled in the art including, for example, conductive inks as described below and conductive pigment materials (e.g., graphite, platinum, gold, and silver loaded polymers that are suitable for use in injection molding and printing techniques).

The electrically conductive contact pads can be any suitable thickness. However, to enable a secure and robust connection to the electrical device, an electrically conductive contact pad thickness in the range of from 5 microns to 5 mm is beneficial, with a thickness of approximately 50 microns being preferred. In this regard, it should be noted that the thickness of the electrically conductive contact pads can be significantly thicker than the electrodes or electrically conductive traces, thus enabling a secure and robust electrical connection between the electrodes and the electrical device (via the electrically conductive traces and the electrically conductive contact pads) while simultaneously providing for the electrodes and electrically conductive traces to be relatively thin.

Electrodes **314** and electrically conductive traces **316** can also be formed from any suitable conductive material including, but not limited to, conductive materials conventionally employed in photolithography, screen printing and flexo-printing techniques. Carbon, noble metals (e.g., gold, platinum and palladium), noble metal alloys, as well as potential-forming metal oxides and metal salts are examples of

5

components that can be included in materials for the electrodes and electrically conductive traces. Conductive ink (e.g., silver conductive ink commercially available as Electrodag® 418 SS from Acheson Colloids Company, 1600 Washington Ave, Port Huron Mich. 48060, U.S.A.) can also be employed to form electrodes **314** and electrically conductive traces **316**. The typical thickness of electrodes **314** and conductive traces **316** is, for example, 20 microns.

For the circumstance of multiple electrodes, each electrode can be formed using the same conductive ink, such as the conductive ink described in International Patent Application PCT/US97/02165 (published as WO97/30344 on Aug. 21, 1997) or from different conductive inks that provide desirable and various characteristics for each of the electrodes.

Laminate layer **318** can also be formed from any suitable material known in the art including, but not limited to, polystyrene, polycarbonate, polymethyl-methacrylate and polyester. Manufacturing of microfluidic analytical systems according to embodiments of the present invention can be simplified when laminate layer **318** is in the form of a pliable and/or flexible sheet. For example, laminate layer **318** can be a pliable sheet with a thickness in the range of from about 5 μm to about 500 μm . In this regard, a laminate thickness of approximately 50 μm has been found to be beneficial with respect to ease of manufacturing. Laminate layer **318** will typically be thinner than insulating substrate **306** and be sufficiently thin that heat can be readily transferred through laminate layer **318** to insulating substrate **306** during the manufacturing of analysis module **302**.

An essentially liquid and/or air tight microchannel can be achieved in microfluidic analytical system **300** when (i) laminate layer **318** is fused with the portion of the upper surface **308** of the insulating substrate **306** such that microchannels **310** are essentially liquid and/or air tight, and/or (ii) having electrodes **314** and/or electrically conductive traces **316** fused with the upper surface **308** of insulating substrate **306** such that microchannels **310** are essentially liquid and/or air tight. Exemplary methods of achieving such fused structures are described in detail below.

FIG. 6 depicts analysis module **302** of microfluidic analytical system **300** connected with an alternative electrical device **304'** that includes three spring contact **320'** (one of which is illustrated in FIG. 6) and a chassis **322'** (see FIG. 6). FIG. 6 illustrates spring contact **320'** connected with accessible exposed surface **326**.

In the embodiment of FIGS. 3, 4, 5 and 6, electrically conductive contact pads **312** are disposed in a recess **328** of upper surface **308**. By locating electrically conductive contact pads **312** in a recess on the upper surface of insulating substrate **306**, electrically conductive contact pads **312** can be easily formed with a thickness that is greater than the thickness of the electrode(s) and electrically conductive contact pads, thus enabling a robust and secure connection to an electrical device from either of a top surface (such as accessible exposed surface **324**) or a side surface (e.g., accessible exposed surface **326**) of the electrically conductive contact pad. However, FIG. 7 depicts an alternative configuration wherein the electrically conductive contact pad is disposed on an essentially planar upper surface of the insulating substrate. FIG. 7 depicts an analysis module **700** of a microfluidic analytical system according to the present invention. Analysis module **700** includes an insulating substrate **706** with an upper surface **708**. Upper surface **708** has microchannel **710** therein.

Analysis module **700** also has electrically conductive contact pad **712** disposed on the upper surface of insulating substrate **706**, an electrode **714** disposed over microchannel

6

710, an electrically conductive trace **716** connected to electrode **714** and electrically conductive contact pad **712** and a laminate layer **718**. Laminate layer **718** is disposed over electrode **714**, electrically conductive trace **716**, and a portion of the upper surface **708** of insulating substrate **706**.

Once apprised of the present disclosure, one skilled in the art will recognize that the analysis module of microfluidic analytical systems according to the present invention can include a plurality of micro-channels, a plurality of electrodes (e.g., a plurality of working electrodes and reference electrodes), a plurality of electrically conductive traces and a plurality of electrically conductive contact pads. In addition, the insulating substrate and laminate layer can be any suitable shape. For example, the insulating substrate and laminate layer can be circular in shape with the electrically conductive contact pad(s) being disposed at the periphery of such a circular insulating substrate.

FIG. 8 is a flow chart depicting stages in a process **800** for manufacturing an analysis module with an accessible electrically conductive contact pad for a microfluidic system. Process **800** includes forming an insulating substrate with an upper surface, at least one microchannel within the upper surface, and at least one electrically conductive contact pad disposed on the upper surface, as set forth in step **810**. FIG. 9A depicts the result of such a forming step as represented by insulating substrate **950**, upper surface **952** of insulating substrate **950**, microchannel **954** and electrically conductive contact pad **956**.

Any suitable technique(s) can be used to conduct step **810**. For example, microchannels can be formed in the upper surface of an insulating substrate by the use of etching techniques, ablation techniques, injection moulding techniques or hot embossing techniques. For the circumstance that an injection moulding technique is employed, insulating polymeric materials (which are known to flow well into moulds under conditions of elevated temperature and pressure) can be employed. Examples of such insulating polymeric materials include, but are not limited to, polystyrene, polycarbonate, polymethylmethacrylate and polyester. Furthermore, the electrically conductive contact pads can be formed using, for example, screen printing of conductive inks or co-moulding of the electrically conductive contact pads during formation of the insulating substrate.

As set forth in step **820** of FIG. 8, a laminate layer with at least one electrode and at least one electrically conductive trace disposed on a bottom surface of the laminate layer is produced. FIG. 9A also depicts the result of such a production step as represented by laminate layer **958**, electrode **960** and conductive trace **962**. The electrode(s) and electrically conductive trace(s) can be formed on the laminate layer by, for example, any suitable conductive ink printing technique known to one skilled in the art.

Subsequently, at step **830** of process **800**, the laminate layer is adhered to the insulating substrate such that:

- (i) at least a portion of the bottom surface of the laminate layer is adhered to at least a portion of the upper surface of the insulating substrate;
- (ii) the electrode(s) is exposed to at least one microchannel;
- (iii) each of the electrically conductive traces is electrically contacted to at least one electrically conductive contact pad, and
- (iv) at least one surface of the electrically conductive contact pad remains exposed and accessible for electrical connection. FIG. 9B depicts the resultant structure of step **830**.

During adhering step **830**, the laminate layer can be fused with the portion of the upper surface of the insulating sub-

strate such that the at least one microchannel is essentially liquid tight and, alternatively, also essentially air tight. Such fusing can be achieved by application of sufficient heat and/or pressure to cause localized softening and/or melting of the laminate layer and insulating substrate. The application of heat and/or pressure can be achieved, for example, via heated rollers. It is postulated, without being bound, that such fusing is due to a physical adhesion and not a chemical bond and that the fusing is a result of surface wetting between the molten states of the laminate layer and insulating layer material(s), and "mechanical keying" in the solid state. Mechanical keying refers to the bonding of two material surfaces via a mechanism that involves the physical penetration of one material into voids that are present in, or developed in, the second material.

To enable fusing and the creation of a liquid tight and/or air tight microchannel, the melting characteristics of the laminate layer and insulating substrate must be predetermined. For example, it can be beneficial for the surface of the laminate layer and insulating substrate to become molten at essentially the same time during the adhering step in order that efficient wetting of the interface between the laminate layer and insulating layer can occur followed by flowing and intermingling of the molten portions of the layers. Subsequent cooling produces a laminate layer that is fused to the portion of the insulating layer above which the laminate layer is disposed in a manner that produces a liquid tight and/or air tight microchannel.

For the circumstance where both the laminate layer and the insulating layer are formed of polystyrene, fusing can occur, for example, at a pressure of 5 Bar and a temperature of 120° C. for 3 seconds. To further enhance the creation of a liquid tight and, alternatively, air tight microchannel, the adhering step can also be conducted such that the electrically conductive traces and/or electrodes are fused with the upper surface of the insulating substrate. In such a circumstance, the material from which the electrically conductive traces (and/or electrodes) are formed is predetermined such that the material fuses with the insulating layers under the same conditions of pressure, temperature and time as for the fusing of the laminate layer and insulating layer. However, the material from which the electrically conductive traces (and/or electrodes) is formed must not lose significant definition during the adhering step.

In addition, to enhance the electrical connection between the electrically conductive traces and the electrically conductive contact pads, the electrically conductive traces and electrically conductive contact pads can be formed of materials (e.g., materials with an excess of conductive pigment) that become fused during the adhering step. However, an electrical connection between the electrically conductive traces and electrically conductive contact pads can also be formed by physical mechanical contact established during the adhering step.

Typical conditions for the adhering step are, for example, a temperature in the range of 80° C. to 200° C., a pressure in the range from about 0.5 Bar to about 10 Bar and a duration of from about 0.5 seconds to about 5 seconds.

EXAMPLE

Manufacturing of an Analysis Module

An embodiment of a microfluidic analytical device according to the present invention was manufactured using an insulating substrate formed from a polystyrene material (i.e., Polystyrol 144C, commercially available from BASF,

Aktiengesellschaft, Business Unit Polystyrene, D-67056 Ludwigshafen, Germany) and a laminate layer formed from another polystyrene material (i.e., Norflex® Film, commercially available from NSW Kunststofftechnik, Norddeutsche Seekabelwerke AG, 26954 Nordenham, Germany).

Electrodes and electrically conductive traces were printed on the laminate layer using a conductive ink. In addition, electrically conductive contact pads were printed on the insulating substrate using the same conductive ink. The conductive ink used to print the electrically conductive traces, electrically conductive contact pads and electrodes had the following mass percent composition:

18.5% micronised powder containing platinum and carbon in a 1:9 mass ratio (e.g., MCA 20V platinized carbon available from MCA Services, Unit 1A Long Barn, North End, Meldreth, South Cambridgeshire, SG8 6NT, U.K.);

19.0% poly(bisphenol A-co-epichlorohydrin)-glycidyl end capped polymer (e.g., Epikote™ 1055, available from Resolution Enhanced Products, Resolution Europe BV, PO Box 606, 3190 AN Hoogvliet Rt, The Netherlands); and 62.5% Methyl Carbitol (Diethylene Glycol Monomethyl Ether) solvent (obtained from Dow Benelux B.V., Prins Boudewijnlaan 41, 2650 Edegem, Belgium).

The conductive ink composition detailed immediately above is particularly beneficial for use with a polystyrene laminate layer and a polystyrene insulating substrate (as described below). However, in general, the composition can be varied while keeping the mass ratio of micronised powder to polymer in the range of about 3:1 to 1:3.

Once apprised of the present disclosure, one skilled in the art will recognize that the percent of solvent in the conductive ink can be varied to suit the technique used to apply the conductive ink to a laminate layer and/or insulating substrate (e.g., spray coating, hot embossing, and flexographic printing). Furthermore, any suitable solvent can be substituted for Methyl Carbitol (Diethylene Glycol Monomethyl Ether) including, for example, alcohols, methyl ethyl ketone, butyl glycol, benzyl acetate, ethylene glycol diacetate, isophorone, and aromatic hydrocarbons.

The insulating substrate was subsequently adhered to the laminate layer under conditions of applied temperature and pressure such that softening and fusing of the laminate layer and insulating layer occurred. The temperature and pressure were applied to the laminate layer and insulating substrate by passing the laminate layer and insulating substrate through heated rollers at a rate in the range of 30 mm/sec to 3 mm/sec.

Furthermore, the temperature and pressure were sufficient to cause softening of the conductive ink and a fusing between the conductive ink and the insulating substrate and fusing between the conductive ink and the laminate layer. Despite such softening and fusing, the conductive ink retained its conductive properties. Therefore, the conductive ink is also referred to as a fusible conductive ink.

Temperatures employed during the adhering step were typically within the range 80° C. to 150° C., and particularly about 120° C. and pressures typically between 1 bar and 10 bar, and particularly about 5 bar.

The adhering step created liquid tight microchannels with no gaps between any points of physical contact between the insulating substrate, laminate layer and conductive ink.

To facilitate optimum fusing it is desirable that the melting point of the conductive ink be within the range +30° C. to -50° C. relative to the melting point of the laminate layer and insulating substrate. Furthermore, it is more desirable that the melting range of the conductive ink be 0° C. to -30° C. relative the melting point of the substrate and preferably the melting range of the ink will be between -5° C. and -15° C.

9

relative to the melting point of the substrate. In this regard, it should be noted that the reported melting point range for Epikote 1055 is between 79° C. and 87° C. and that the melting point of the polystyrene from which the laminate layer and insulating substrate were formed is 90° C.

Furthermore, to facilitate fusing between components formed from a conductive ink (e.g., electrodes, electrically conductive traces and electrically conductive contact pads) and an insulating substrate or laminate layer, it can be beneficial to employ a conductive ink that includes components with a molecular weight that are lower than the molecular weight of a polymeric material from which the insulating substrate and laminate layer may be are formed.

It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that structures within the scope of these claims and their equivalents be covered thereby.

That which is claimed is:

1. A fusible conductive ink for use in manufacturing microfluidic analytical system, the fusible conductive ink consisting essentially of:

10

micronised powder containing platinum and carbon;
poly(bisphenol A-co-epichlorohydrin)-glycidyl end capped polymer; and
a solvent,

wherein the ratio of micronised powder to poly(bisphenol A-co-epichlorohydrin)-glycidyl end capped polymer is in the range of 3:1 to 1:3.

2. The fusible conductive ink of claim 1, wherein the micronised powder contains platinum and carbon in a mass ratio of approximately 1:9.

3. The fusible conductive ink of claim 1, wherein the solvent is Methyl Carbitol (Diethylene Glycol Monomethyl Ether).

4. The fusible conductive ink of claim 1, wherein the fusible conductive ink has a mass percent composition as follows:

18.5% micronised powder containing platinum and carbon in a 1:9 mass ratio;

19.0% poly (bisphenol A-co-epichlorohydrin)-glycidyl end capped polymer; and

62.5% Methyl Carbitol (Diethylene Glycol Monomethyl Ether) solvent.

* * * * *