

SUBSTRATE WITH LIQUID ELECTRODE

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Background of the Invention

[0001] Liquid metal micro switches (LIMMS) have been made that use a liquid metal, such as mercury, as the switching fluid. The liquid metal may make and break electrical contacts. To change the state of the switch, a force is applied to the switching fluid, which causes it to change form and move. However, the movement of the mercury over the contacts can sometimes decrease the reliability of the switch.

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Summary of the Invention

[0002] In one embodiment, a substrate is disclosed that comprises a first layer and a second layer. An electrode is deposited on the first layer. The first layer is mated to the second layer. The second layer defines a duct that leads from the first electrode to a surface of the second layer opposite the first electrode. A liquid electrode fills at least a portion of the duct.

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Brief Description of the Drawings

5 **[0003]** Illustrative embodiments of the invention are illustrated in the drawings in which:

[0004] FIG. 1 illustrates an elevation of a first exemplary embodiment of a first layer and a second layer that may be used in a substrate for a fluid-based switch;

10 **[0005]** FIG. 2 illustrates the first and second layers of FIG. 1 mated together to form a substrate that may be used in a fluid-based switch;

[0006] FIG. 3 illustrates an exemplary method for making a substrate such as that depicted in FIG. 2;

[0007] FIG. 4 illustrates a second exemplary embodiment of a substrate
15 that may be used in a fluid-based switch;

[0008] FIG. 5 illustrates a plan view of a third exemplary embodiment of a substrate that may be used in a fluid-based switch;

[0009] FIG. 6 illustrates an elevation of the substrate shown in FIG. 5;

[0010] FIG. 7 illustrates a perspective view of a first exemplary
20 embodiment of a switch that may use a substrate including ducts; and

[0011] FIG. 8 illustrates an elevation of the switching fluid cavity of the switch shown in FIG. 7.

Detailed Description

[0012] FIGS. 1 and 2 illustrate a substrate 100 that may be used in a fluid-based switch such as a LIMMS. As illustrated by the method set forth in FIG. 3, the substrate 100 may be produced by depositing 300 a number of electrodes 112, 114, 116 on a first layer 101. By way of example, the electrodes may be solid electrodes and the first layer may be formed from (or comprise) a ceramic material. Other suitable materials may also be used, such as polymer or glass.

[0013] Next, a liquid electrode 122, 124, 126 is deposited 305 on each of the previously deposited electrodes 112, 114, 116. In one embodiment, the liquid electrodes may be a liquid metal electrodes, such as mercury electrodes. As will be described in further detail below, the liquid electrodes may be used in conjunction with a switching fluid in a fluid-based switch to make and break contact connections between the electrodes 112, 114, 116.

[0014] The second layer 103 defines a plurality of ducts 104, 106, 108. These ducts are aligned 310 with the electrodes 112, 114, 116, 122, 124, 126 deposited on the first layer 101 so that when the layers are mated together 315, each of the liquid electrodes 122, 124, 126 is forced through at least a portion of the duct with which it is aligned.

[0015] The substrate 100 may be used in a fluid-based switch such as a LIMMS. The ducts 104, 106, 108 may be used to help prevent switching fluid used in the switch from moving over the electrodes 112, 114, 116 as the switching fluid makes and breaks contact between the electrodes. By way of example, the ducts 104, 106, 108 may be tapered, so that an opening of the duct at its respective electrode 112, 114, 116 is wider than an opening of the duct at

the surface of the second layer opposite the electrodes 112, 114, 116. In a fluid-based switch, switching fluid above the ducts may then make and break connections between the electrodes 112, 114, 116 by merging with the liquid electrodes 122, 124, 126 rather than by wetting and rewetting the electrodes 112, 114, 116. This can increase the reliability of the switch. If the ducts are tapered, the tapered shape of the ducts tends to cause the liquid electrodes 122, 124, 126 to remain within their respective ducts 104, 106, 108 and not move over the electrodes 112, 114, 116, thus increasing the reliability of the switch.

[0016] In one embodiment, the walls of the ducts may be lined with a wettable material to help the liquid electrodes 122, 124, 126 wet to the ducts 104, 106, 108. By way of example, the material of the second layer 103 may be formed from (or comprise) glass. However, the second layer could also be formed from materials such as polymers or ceramics. The ducts may be made wettable by metallizing the glass defining the ducts (e.g., via sputtering).

[0017] In some environments, it may be difficult to form tapered ducts such as those depicted in FIG. 1. An alternate substrate that may be used in a fluid-based switch to help reduce the movement of switching fluid over electrodes is therefore depicted in FIG. 4. The substrate 400 includes a first layer 401, a second layer 403 mated to the first layer 401, and a third layer 405 mated to the second layer 403. By way of example, the first layer may be formed from (or comprise) ceramic, and the second and third layers may be formed from (or comprise) glass or ceramic. Other suitable materials are also contemplated.

[0018] The second layer 403 defines a plurality of ducts 402, 404, 406 leading from electrodes 422, 424, 426 deposited on the first layer 401 to the surface of the second layer opposite the electrodes 422, 424, 426. The third

layer defines extensions 412, 414, 416 of the ducts 402, 404, 406 that lead from the surface of the second layer to an opposite surface of the third layer. The extensions of the ducts 412, 414, 416 are narrower than the ducts 402, 404, 406. Liquid electrodes (e.g., mercury electrodes) 432, 434, 436 fill at least a portion of each of the ducts. At least a portion of the walls of the ducts defined by the second layer 403 and the third layer 405 may be lined with a wettable material to help the liquid electrodes 432, 434, 436 wet to the ducts 402, 404, 406.

[0019] In one embodiment, the substrate 400 may be used in a fluid-based switch. The shape of the ducts formed through the second and third layers of the substrate may cause the liquid electrodes 432, 434, 436 deposited within each of the ducts to remain within the duct as switching fluid makes and breaks contact between electrodes 422, 424, 426, thus increasing the reliability of the switch.

[0020] The substrate of FIG. 4 may be formed using a process similar to that described in FIG. 3. Prior to mating 315 the second layer 403 to the first layer 401, the smaller diameter ducts 412, 414, 416 of the third layer 405 may be aligned with the ducts 402, 404, 406 of the second layer 403, and the third layer 405 may be mated to the second layer 403.

[0021] FIGS. 5 and 6 illustrate a third exemplary embodiment of a substrate 500 that may be used in a fluid-based switch. A plurality of electrodes 522, 524, 526 are deposited on a first layer 501 of the substrate. A second layer 503 is then mated to the first layer 501. By way of example, the second layer may be formed from (or comprise) glass, and the first layer may be formed from (or comprise) a ceramic material. Other suitable materials are also contemplated.

[0022] The second layer defines a plurality of ducts 514, 516, 518 that lead from the electrodes 522, 524, 526 to a surface of the second layer 503 opposite the electrodes 522, 524, 526. The ducts comprise a bell shape, with the openings of the ducts at the electrodes being wider than the openings of the ducts at the opposite surface of the second layer. The bell shape may have a variety of profiles and may be formed, for example, by masking the second layer and then sandblasting the bell shape(s) into the second layer. Optionally, indentations 504, 506, 508 defined by the second layer may be used to recede the openings of the ducts from the surface of the second layer. The indentations have a diameter larger than that of the ducts at the surface of the second layer. It should be appreciated that alternate embodiments may not have the indentations depicted in FIG. 6.

[0023] Liquid electrodes (e.g., mercury electrodes) 534, 536, 538 fill at least a portion of each of the ducts. The walls of the ducts may be lined with a wettable material to help the liquid electrodes 534, 536, 538 wet to the ducts. The indentations may also be lined with a wettable material so that a switching fluid used in a fluid-based switch may wet to the indentations.

[0024] In one embodiment, the substrate 500 is used in a fluid-based switch. The shape of the ducts 514, 516, 518 may cause the liquid electrodes 534, 536, 538 deposited within each of the ducts to remain within their respective ducts as a switching fluid makes and breaks connections between the electrodes 522, 524, 526. The indentations 504, 506, 508 provide a greater contact area for the liquid electrodes 534, 536, 538, and the recessed edges of the indentations may help prevent the wettable linings from lifting their edges and moving out of the indentations.

[0025] FIGS. 7 and 8 illustrate a first exemplary embodiment of a fluid-based switch. The switch 700 comprises a first substrate, having a first layer 501 and a second layer 503. A second substrate 702 is mated to the first substrate 501/503. The substrates 501/503, 702 define between them a number of
5 cavities 704, 706, 708.

[0026] The second layer 503 defines a number of ducts 534, 536, 538 (FIG. 8), each of which leads from at least one of the cavities to one of a plurality of electrodes 522, 524, 526 on the first layer 501 of the substrate. A switching fluid 712 (e.g., a conductive liquid metal such as mercury) is held within the ducts
10 534, 536, 538 and one or more of the cavities (e.g., cavity 706). The switching fluid 712 serves to open and close at least a pair of the plurality of electrodes 522, 524, 526 in response to forces that are applied to the switching fluid 712. An actuating fluid 710 (e.g., an inert gas or liquid) held within one or more of the cavities (e.g., cavities 704, 708) serves to apply the forces to the switching fluid
15 712.

[0027] Portions of the first substrate 702 may be metallized for the purpose of creating "seal belts" 714, 716, 718. The creation of seal belts 714-718 within a cavity 706 holding switching fluid 712 provides additional surface areas to which the switching fluid 712 may wet. This not only helps in latching the various states
20 that a switching fluid can assume, but also helps to create a sealed chamber from which the switching fluid cannot escape, and within which the switching fluid may be more easily pumped (i.e., during switch state changes).

[0028] In one embodiment of the switch 700, the forces applied to the switching fluid 712 result from pressure changes in the actuating fluid 710. The
25 pressure changes in the actuating fluid 710 impart pressure changes to the

switching fluid 712, and thereby cause the switching fluid 712 to change form, move, part, etc. In FIG. 7, the pressure of the actuating fluid 710 held in cavity 704 applies a force to part the switching fluid 712 as illustrated. In this state, the rightmost pair of electrodes 524, 526 of the switch 700 are coupled to one
5 another (see FIG. 8). If the pressure of the actuating fluid 710 held in cavity 704 is relieved, and the pressure of the actuating fluid 710 held in cavity 708 is increased, the switching fluid 712 can be forced to part and merge so that electrodes 524 and 526 are decoupled and electrodes 522 and 524 are coupled.

[0029] As the switch changes state, the liquid electrodes 514, 516, 518
10 (i.e., portions of the switching fluid 712) tend to remain within the ducts 534, 536, 538 so that the switching fluid 712 does not have to wet and rewet the electrodes 522, 524, 526. Thus, the movement of the switching fluid over the electrodes is at least decreased, and preferably eliminated. As described elsewhere in this application, the ducts may be tapered, bell-shaped, or of any other shape that
15 tends to cause the liquid electrodes 514, 516, 518 to remain wetted to the electrodes 522, 524, 526. The second layer 503 may further define indentations at the openings of the ducts within the cavities 704, 706, 708, for purposes previously described.

[0030] Pressure changes in the actuating fluid 710 may be achieved by
20 means of heating the actuating fluid 710, or by means of piezoelectric pumping. The former is described in U.S. Patent #6,323,447 of Kondoh et al. entitled "Electrical Contact Breaker Switch, Integrated Electrical Contact Breaker Switch, and Electrical Contact Switching Method", which is hereby incorporated by reference for all that it discloses. The latter is described in U.S. Patent
25 Application Serial No. 10/137,691 of Marvin Glenn Wong filed May 2, 2002 and

entitled "A Piezoelectrically Actuated Liquid Metal Switch", which is also incorporated by reference for all that it discloses. Although the above referenced patent and patent application disclose the movement of a switching fluid by means of dual push/pull actuating fluid cavities, a single push/pull actuating fluid cavity might suffice if significant enough push/pull pressure changes could be imparted to a switching fluid from such a cavity. Additional details concerning the construction and operation of a switch such as that which is illustrated in FIGS. 7 & 8 may be found in the afore-mentioned patent of Kondoh.

[0031] While illustrative and presently preferred embodiments of the invention have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed. For example, a substrate similar to that shown in FIGS. 1, 2, or 4-6 may also be used in an optical switch that uses an opaque liquid to open or block light paths. The appended claims are intended to be construed to include such variations, except as limited by the prior art.

Foreign Claims

1. A substrate (100) comprising:
 - a first layer (101);
 - a first electrode (112) deposited on the first layer;
 - a second layer (103) mated to the first layer, the second layer defining a duct (104) leading from the first electrode to a surface of the second layer that is opposite the first electrode; and
 - a liquid electrode (122) filling at least a portion of the duct.
2. The substrate of claim 1, wherein an opening of the duct at the first electrode is wider than an opening of the duct at the surface of the second layer.
3. The substrate of claim 2, wherein the duct comprises a bell shape (514).
4. The substrate of any of claims 1-3, wherein the second layer of the substrate comprises an indentation (504) at an opening of the duct at the surface of the second layer, the indentation having a diameter that is larger than that of the duct at the surface of the second layer.
5. The substrate of claim 4, further comprising a wettable material lining walls of the duct.
6. The substrate of any of claims 1-5, wherein the second layer comprises glass and the wettable material comprises metal.
7. The substrate of any of claims 1-5, wherein the second layer comprises ceramic and the wettable material comprises metal.
8. The substrate of any of claims 1-7, wherein the first electrode is a solid electrode.

9. The substrate of any of claims 1-8, further comprising a third layer (405) mated to the second layer, the third layer defining an extension (412) of the duct leading from the surface of the second layer to an opposite surface of the third layer, the extension of the duct being narrower than the duct.

10. A switch (700) comprising:

a first substrate having a first layer (501) and a second layer (503), the first layer having a plurality of electrodes (522, 524, 526) deposited thereon, and the second layer defining a number of ducts (514, 516, 518);

a second substrate (702) mated to the first substrate, the first substrate and the second substrate defining therebetween at least portions of a number of cavities (704, 706, 708), each duct of the second layer leading from at least one of the cavities to one of the plurality of electrodes deposited on the first layer;

a switching fluid (718), held within one or more of the ducts and one or more of the cavities, at least a portion of which is movable to open and close at least a pair of the plurality of electrodes in response to forces that are applied to the switching fluid; and

an actuating fluid (710), held within one or more of the cavities, that applies the forces to the switching fluid.