



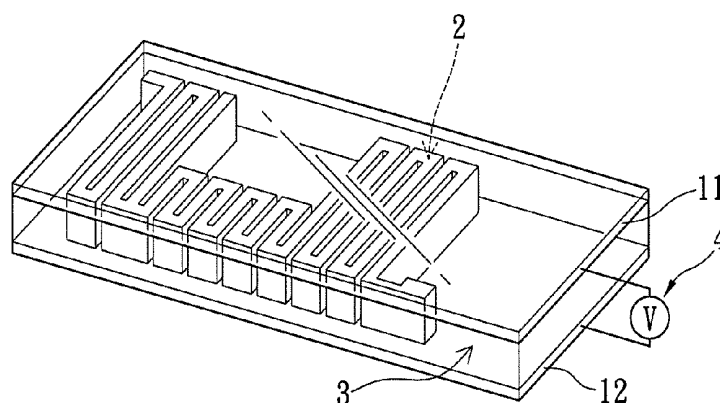
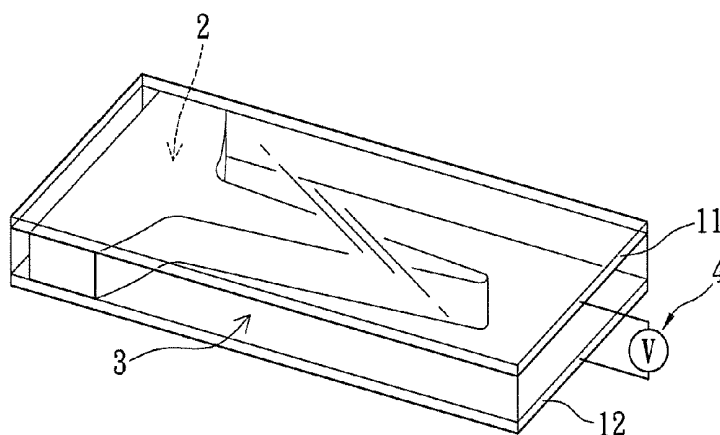
US 20110297547A1

(19) **United States**(12) **Patent Application Publication**
FAN et al.(10) **Pub. No.: US 2011/0297547 A1**(43) **Pub. Date: Dec. 8, 2011**(54) **VIRTUAL CHANNEL PLATFORM**(30) **Foreign Application Priority Data**(75) Inventors: **SHIH-KANG FAN**, Hsinchu (TW);
WEN-JUNG CHEN, Tainan City
(TW)

Jan. 14, 2009 (TW) 098101187

Publication Classification(73) Assignee: **NATIONAL CHIAO TUNG**
UNIVERSITY, Hsinchu (TW)(51) **Int. Cl.**
C25B 7/00 (2006.01)(52) **U.S. Cl.** **204/643; 204/600**(57) **ABSTRACT**(21) Appl. No.: **13/214,390**(22) Filed: **Aug. 22, 2011****Related U.S. Application Data**(63) Continuation-in-part of application No. 12/385,771,
filed on Apr. 20, 2009.

A virtual channel platform is disclosed. Said virtual channel platform comprises two spaced electrode plates, which can provide an electric field, and a voltage source electrically connected to the two electrode plates. Said plates define a virtual reservoir and a virtual channel. When the voltage source provides a voltage between the electrode plates, the electric field generates a force to drive a driven fluid streaming from the virtual reservoir to the virtual channel, allowing the virtual channel to be filled with the driven fluid fully.



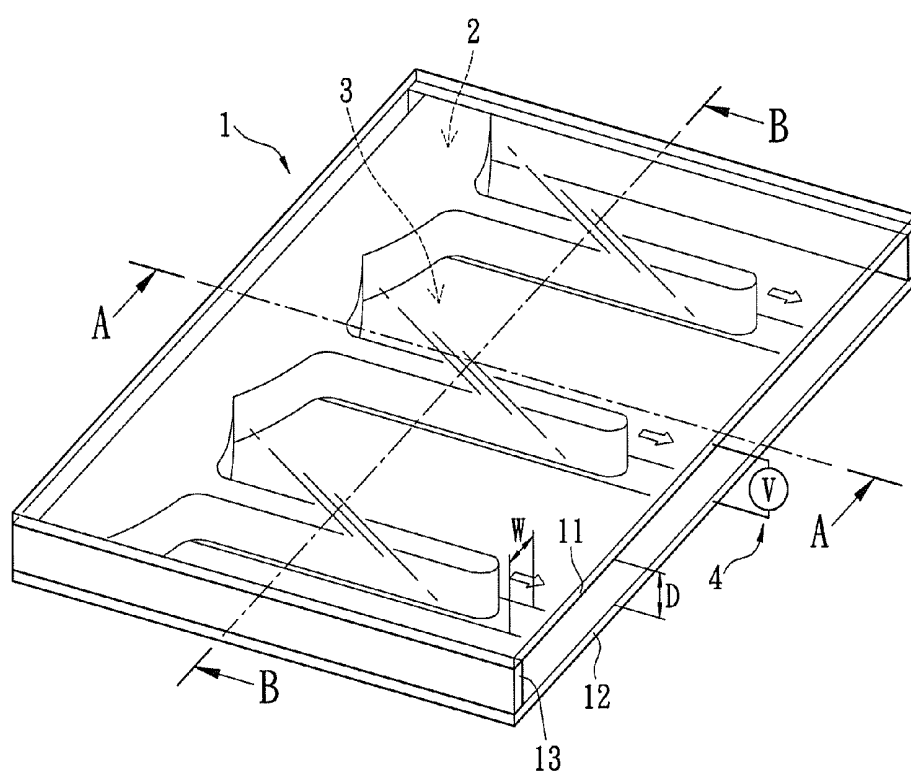


FIG. 1

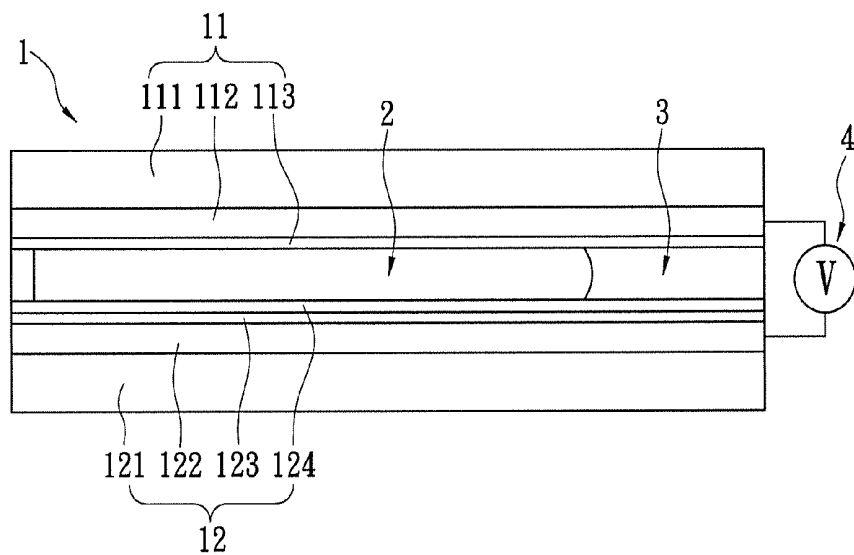


FIG. 1A

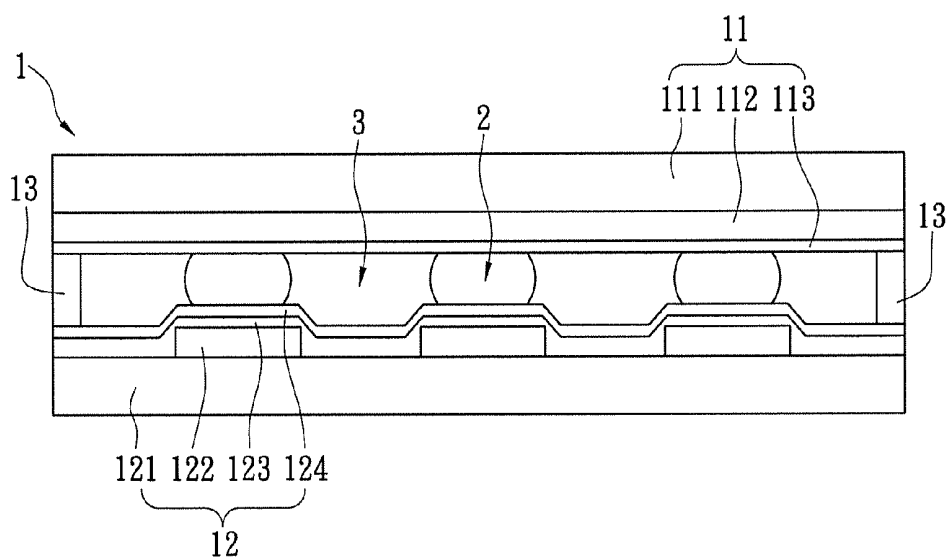


FIG. 1B

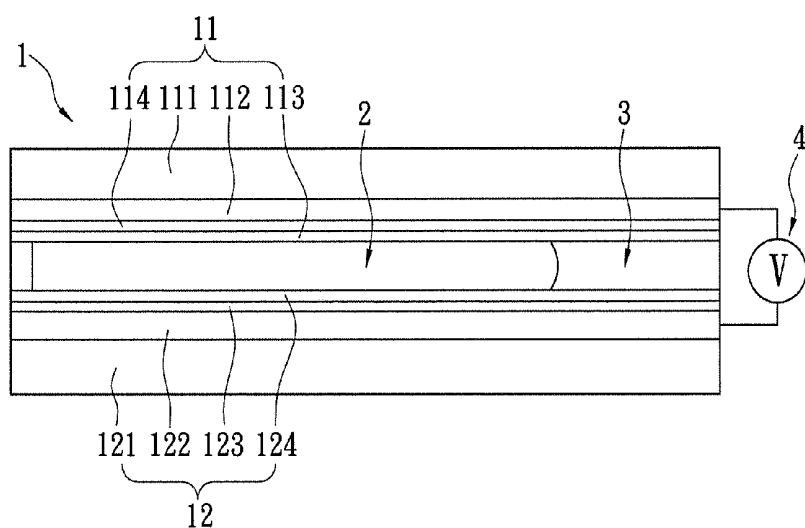


FIG. 1C

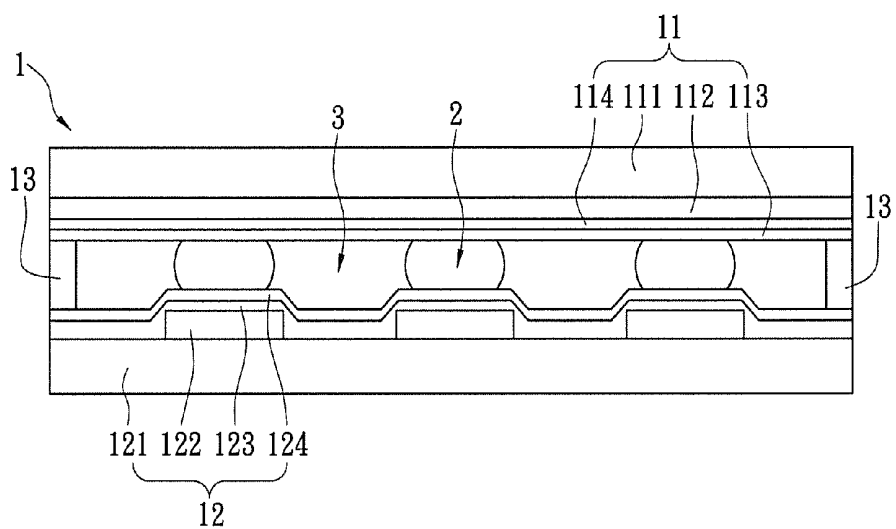
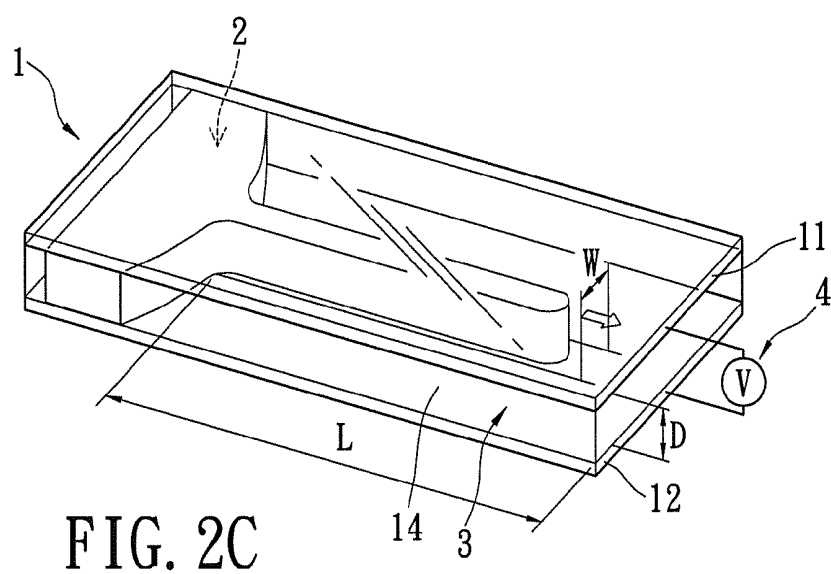
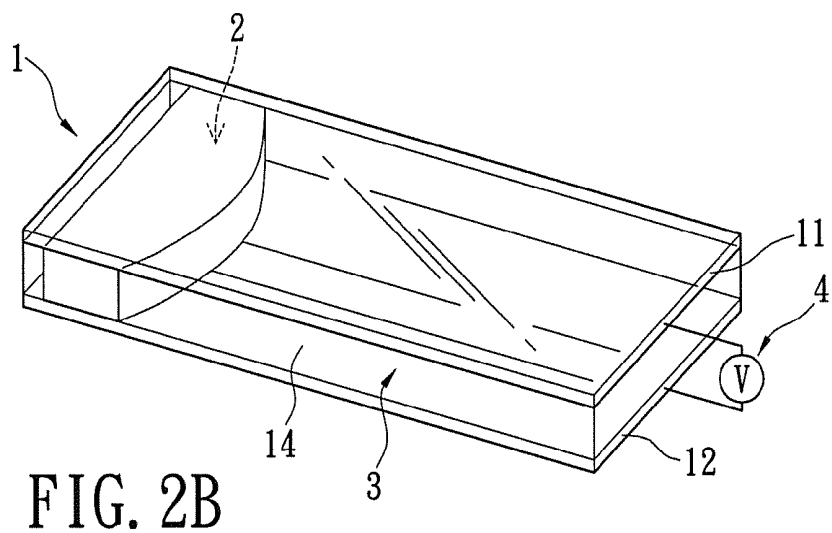
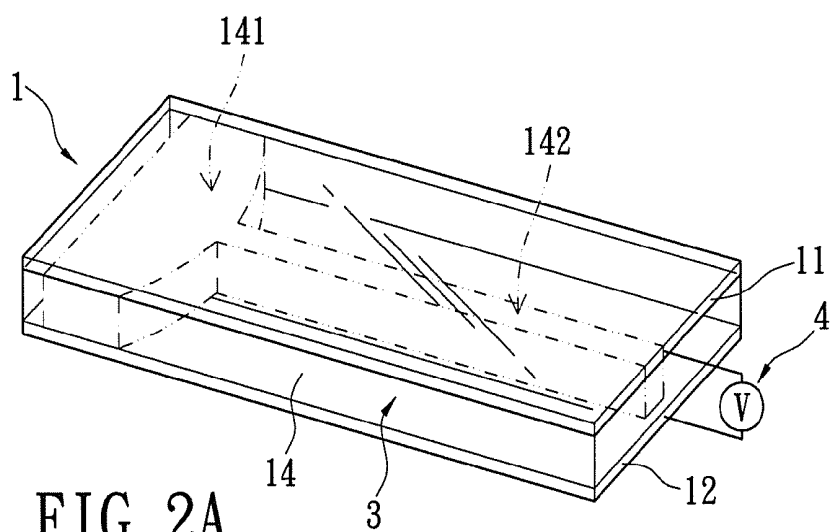


FIG. 1D



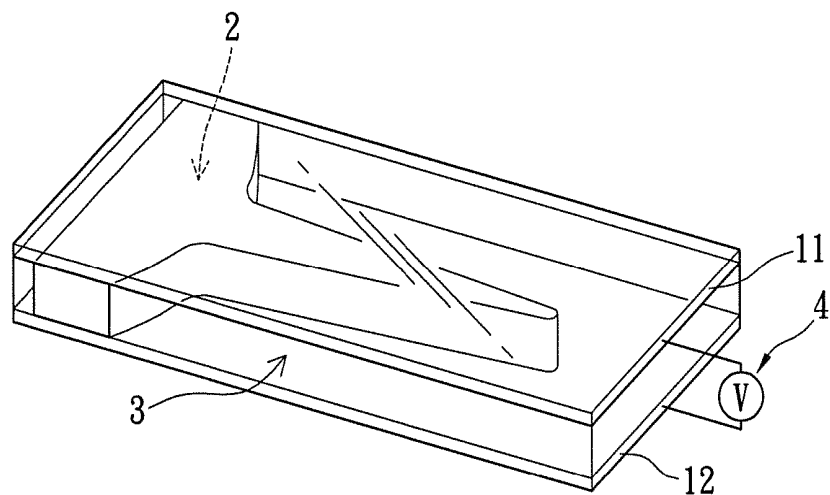


FIG. 3A

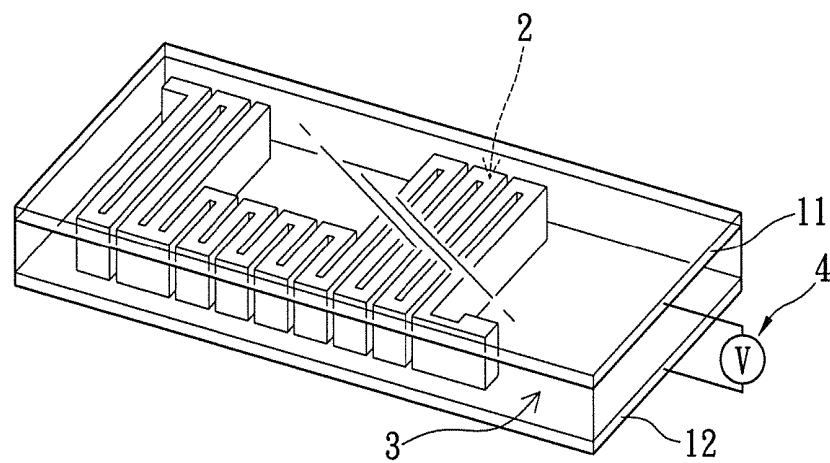


FIG. 3B

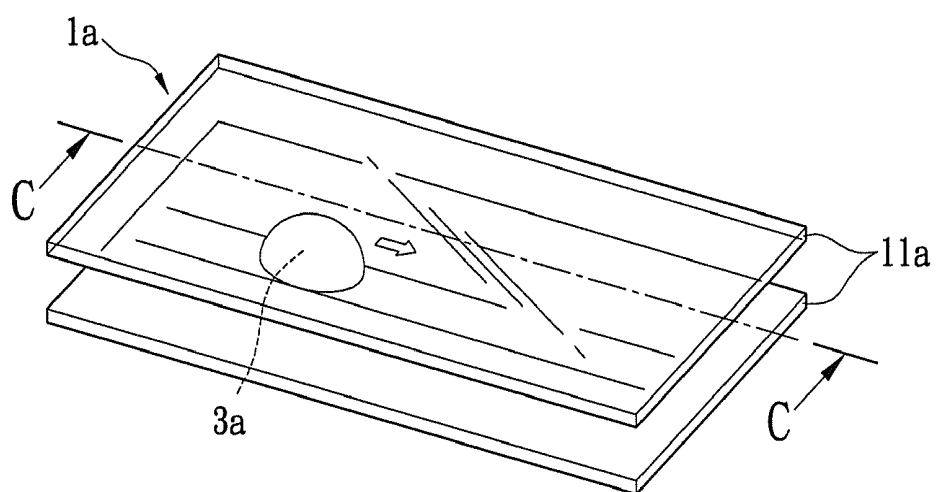


FIG. 4A
PRIOR ART

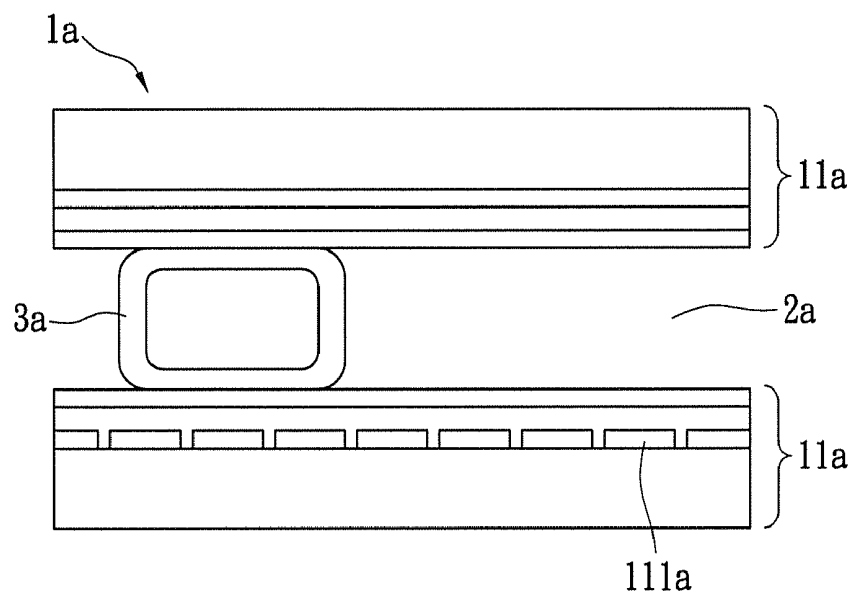


FIG. 4B
PRIOR ART

VIRTUAL CHANNEL PLATFORM

RELATED U.S. APPLICATION DATA

[0001] This Application is being filed as a Continuation-in-part of U.S. patent application Ser. No. 12/385,771, filed on Apr. 20, 2009, currently pending.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The instant disclosure relates generally to a platform for fluidic manipulations, more particularly, to a platform to controllably pump fluids in an electric-field-formed virtual channel without physical channel walls. Even more particularly, the instant disclosure relates to a platform for fluid pumping and fluid formation by dielectrophoresis.

[0004] 2. Description of Related Art

[0005] Pumping liquids in microchannels is essential to the study of microfluidics and practical to the wide applications including lab-on-a-chip (LOC) and micro total analysis systems (μ TAS).

[0006] Various microfabrication techniques have been developed to carve and seal microchannels on silicon, glass, or polymer substrates. To drive liquids in microchannels, different pumping mechanisms have been investigated. For example, mechanical micropumps transport liquids through hydraulic pressure differences, while non-mechanical electroosmotic pumping relies on the zeta potential on the channel wall and electric potential difference across the liquid in a microchannel.

[0007] Although the microfabricated physical channel walls assist pumping in a mechanical or/and electrical way(s) as described above, they eliminate the controllability of the liquid streams during operation for different applications. In addition, the fabrication and sealing of the microchannels are usually complicated. The problems of liquid leakage and dead volume are commonly observed.

[0008] Please refer to FIGS. 4A and 4B, which show a conventional droplet manipulation platform 1a. The droplet manipulation platform 1a has two electrode plates 11a. One of the electrode plates 11a has a plurality of discrete electrodes 111a so as to define a fluidic space 2a between plates. The fluidic space 2a is only used for the passing through of a droplet 3a by utilizing the discrete electrodes 111a. However, in practice, the droplet manipulation platform 1a has some limitations, such as liquid in the droplet manipulation platform 1a cannot be applied to capillary electrophoresis or light guidance which is usually performed along a continuous liquid channel complicatedly carved and sealed on silicon, glass, or polymer substrate.

[0009] Hence, the inventors of the instant disclosure believe that the shortcomings described above are able to be improved and finally suggest the instant disclosure which is of a reasonable design and is an effective improvement based on deep research and thought.

SUMMARY OF THE INVENTION

[0010] An object of the instant disclosure is to provide a virtual channel platform which has no substantial flow channel and drives fluid surrounded by immiscible filling fluid(s) based on an electric field. With no substantial flow channels, the platform is easily manufactured.

[0011] Another object of the instant disclosure is to provide a virtual channel platform flexibly controlling and delivering fluids without substantial flow channels and moving components (valves or pumps).

[0012] To achieve the above-mentioned objects, a virtual channel platform in accordance with the instant disclosure is provided. The virtual channel platform includes a first and a second electrode plates spaced for forming an electric field, with the first electrode plate having a first substrate and a conductive layer disposed on the first substrate, with the second electrode plate having a second substrate and a patterned conductive electrode disposed on the second substrate. While the conductive layer and the patterned conductive electrode define a virtual reservoir and a virtual channel in communication with the virtual reservoir; a voltage source electrically connected to the conductive layer and the patterned conductive electrode; and a main driven fluid and a surrounding fluid arranged between the first and the second electrode plates, with the surrounding fluid being immiscible with the main driven fluid, and the main driven fluid is arranged in the virtual reservoir. When the voltage source provides a voltage between the conductive layer and the patterned conductive electrode, the electric field generates a force to drive the main driven fluid streaming from the virtual reservoir to the virtual channel, so as to fill the virtual channel with the main driven fluid.

[0013] Advantageously, the operating frequency of the voltage is greater than the cutoff frequency of the virtual channel platform.

[0014] Advantageously, the electric field established by the two electrode plates generates a dielectrophoretic force in order to drive the main driven fluid of a higher dielectric constant along the strong electric field into the region of lower permittivity, i.e., the surrounding fluid, in the planar passage-way.

[0015] Consequently, the virtual channel platform of the instant disclosure has the merits as follows: the virtual channel platform of the instant disclosure has a simple structure and has no moving component, and the virtual channel platform may be manufactured via a simple lithography process without complex channel structures and packaging; furthermore, the virtual channel platform of the instant disclosure can drive the main driven fluid by voltage applications at different frequencies to achieve programmable operation and control.

[0016] Additionally, the virtual channel platform of the instant disclosure does not need an enclosed substantial flow channel, and doesn't need a moving component (valve or pump) to drive the main driven fluid.

[0017] To further understand features and technical contents of the instant disclosure, please refer to the following detailed description and drawings related the instant disclosure. However, the drawings are only to be used as references and explanations, not to limit the instant disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 is a perspective view of a virtual channel platform of the instant disclosure;

[0019] FIG. 1A is a cross-sectional view of the virtual channel platform of the instant disclosure taken along line A-A in FIG. 1;

[0020] FIG. 1B is a cross-sectional view of the virtual channel platform of the instant disclosure taken along line B-B in FIG. 1;

[0021] FIG. 1C is a cross-sectional view of an embodiment of the virtual channel platform of the instant disclosure taken along line A-A in FIG. 1;

[0022] FIG. 1D is a cross-sectional view of the embodiment of the virtual channel platform of the instant disclosure taken along line B-B in FIG. 1;

[0023] FIG. 2A is a schematic view of the virtual channel platform without the main driven fluid of the instant disclosure;

[0024] FIG. 2B is a schematic view of the virtual channel platform of the instant disclosure in operation;

[0025] FIG. 2C is a schematic view of the virtual channel platform of the instant disclosure in another operation state;

[0026] FIG. 3A is a schematic view of a main driven fluid filled in the virtual channel that is in a tapered shape of the instant disclosure;

[0027] FIG. 3B is another schematic view of the main driven fluid filled in the virtual channel that is in a meandered-shape of the instant disclosure;

[0028] FIG. 4A is a perspective view of a droplet channel platform of the related art; and

[0029] FIG. 4B is a cross-sectional view of the droplet channel platform of the related art taken along line C-C in FIG. 4A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0030] Please refer to FIGS. 1, 1A, and 1B, which illustrate a virtual channel platform 1 according to the instant disclosure, into which a main driven fluid 2 is injected. When the virtual channel platform 1 generates an electric field, the main driven fluid 2 located in the virtual channel platform 1 moves in the virtual channel platform 1 under the influence of the electric field. More specifically, the virtual channel platform 1 includes two electrode plates 11, 12 and at least two spacers 13. When a voltage is applied to the two electrode plates 11, 12, the two electrode plates 11, 12 will generate an electric field. The spacers 12 are disposed between the two electrode plates 11, 12.

[0031] Specifically, the two electrode plates 11, 12 are a first electrode plate 11 (hereafter referred as the upper electrode plate 11) and a second electrode plate 12 (hereafter referred as the lower electrode plate 12). Please refer to FIG. 1B, the upper electrode plate 11 further includes a first substrate 111, a conductive layer 112 disposed on a surface of the first substrate 111 and a first hydrophobic layer 113 disposed on a surface of the conductive layer 112. The first substrate 111 may be made of glass, silicon, poly-dimethylsiloxane (PDMS), polyethylene terephthalate (PET), polyethylene naphthalate (PEN), a flexible polymer, and so on. The conductive layer 112 and the first hydrophobic layer 113 can be manufactured by semiconductor manufacturing technologies, e.g. thin film manufacturing technology. Furthermore, the conductive layer 112 may be made of metal, e.g., copper-chromium, oxide, Indium Tin Oxide (ITO), or conductive polymers. The conductive layer 112 can be deposited on the surface of the first substrate 111 by physical vapor deposition including sputtering and evaporation. Furthermore, the material of the first hydrophobic layer 113 can be Teflon coated on the surface of the conductive layer 112 by spin coating. Besides the spun Teflon, the first hydrophobic layer 113 may also be manufactured by other materials and other processes, including chemical or physical vapor deposition, self-assembled formation of lipid surface monolayer and so on. It

must be mentioned that the first hydrophobic layer 113 is optionally disposed on the conductive layer 112 to facilitate handling of the main driven fluid 2 and produces a hydrophobic surface characteristic, thereby being convenient for driving the main driven fluid 2. The formation of the virtual channel and fluid pumping phenomenon may also occur on a virtual channel platform 1 without the first hydrophobic layer 113. Additionally, if the main driven fluid 2 does not wet the surface of the conductive layer 112, the first hydrophobic layer 113 may not necessary.

[0032] Further, it is worthy to mention that the material of the conductive layer 112 is not limited to copper-chromium metal or Indium Tin Oxide, and it may be any one of conductive metal materials, conductive polymer materials or conductive oxide materials.

[0033] In addition, Please refer to FIGS. 1C and 1D, the upper electrode plate 11 further includes a first dielectric layer 114 disposed on a surface of the conductive layer 112. The first hydrophobic layer 113 is disposed on a surface of the dielectric layer 114. The material of the first dielectric layer 114 may be parylene, a positive photoresist, a negative photoresist or a material with a high dielectric constant, or a material with a low dielectric constant, and the above material may be coated on the conductive layer 112 by spin coating, chemical or physical vapor deposition, sol-gel, or other thin film manufacturing technologies. It is worthy to mention that first dielectric layer 114 is optionally disposed on the upper electrode plate 11 according to the electric characteristic of the main driven fluid 2; that is, first dielectric layer 114 may be disposed on the upper electrode plate 11; or first dielectric layer 114 need not to be disposed on the upper electrode plate 11 since the electric characteristic of the main driven fluid 2 can meet the demands of the user.

[0034] The lower electrode plate 12 further includes a second substrate 121, a patterned conductive electrode 122 disposed on a surface of the second substrate 121, a second dielectric layer 123 disposed on the patterned conductive electrode 122 and the second substrate 121, and a second hydrophobic layer 124 disposed on a surface of the second dielectric layer 123. The second substrate 121 may be a substrate plate made of glass, silicon, poly-dimethylsiloxane (PDMS), polyethylene terephthalate (PET), polyethylene naphthalate (PEN), a flexible polymer, and so on. The patterned conductive electrode 122, the second dielectric layer 123, and the second hydrophobic layer 124 can be manufactured by semiconductor manufacturing technologies.

[0035] Furthermore, the patterned conductive electrode 122 is not fixed in shape, which may be rectangle-shaped, strip-shaped, tapered, circular-shaped, meander-shaped, or formed in any other shapes. The shape of the patterned conductive electrode 122 is determined based on user's demands. Also, the patterned conductive electrode 122 may be made of copper-chromium metal or Indium Tin Oxide (ITO), deposited by physical vapor deposition, including sputtering and evaporation. The material of the second dielectric layer 123 may be parylene, a positive photoresist, a negative photoresist or a material with a high dielectric constant, or a material with a low dielectric constant, and the above material may be coated on the patterned conductive electrode 122 by spin coating, chemical or physical vapor deposition, sol-gel, or other thin film manufacturing technologies. It is worthy to mention that the second dielectric layer 123 is optionally disposed on the lower electrode plate 12 according to the electric characteristic of the main driven fluid 2; that is, the

second dielectric layer 123 may be disposed on the lower electrode plate 12; or the second dielectric layer 123 need not to be disposed on the lower electrode plate since the electric characteristic of the main driven fluid 2 can meet the demands of the user. Furthermore, the material of the second hydrophobic layer 124 is Teflon, and Teflon may also be coated on the surface of the conductive layer 112 by spin coating. Besides spin coating of Teflon, the second hydrophobic layer 124 may also be manufactured by other materials with other processes, including chemical or physical vapor deposition, self-assembled monolayer, and so on.

[0036] It must be explained that the second hydrophobic layer 124 is optionally disposed on the second dielectric layer 123 to facilitate liquid handling of the main driven fluid 2. The formation of the virtual channel and fluid pumping phenomenon may also occur on a virtual channel platform 1 without the second hydrophobic layer 124. Additionally, if the main driven fluid 2 does not wet the surface of the second dielectric layer 123, the second hydrophobic layer 124 may be not coated. Furthermore, if the second dielectric layer 123 is not necessary for the electric characteristic of the main driven fluid 2 and the main driven fluid 2 does not wet the surface of the conductive layer 122, the second hydrophobic layer 124 and the second dielectric layer 123 may be not coated.

[0037] Furthermore, the material of the patterned conductive electrode 122 is not limited to copper-chromium metal or Indium Tin Oxide, and it may be any one of conductive metal materials, conductive polymer materials, or conductive oxide materials.

[0038] The at least two spacers 13 are disposed between the upper electrode plate 11 and the lower electrode plate 12. The at least two spacers 13 may be insulating gaskets so as to separate the upper electrode plate 11 from the lower electrode plate 12 for forming a planar passageway 14 into which the main driven fluid 2 is injected. A surrounding fluid 3 is also injected into the planar passageway 14 for encompassing the main driven fluid 2.

[0039] It is worthy to be mentioned that the surrounding fluid 3 is immiscible with the main driven fluid 2. The main driven fluid 2 and the surrounding fluid 3 are selected according to dielectric constants, as long as the dielectric constant of the main driven fluid 2 is greater than that of the surrounding fluid 3. So the main driven fluid 2 may be aqueous solution (such as water) and the surrounding fluid 3 may be air or organic solution (such as silicone oil); alternatively, the main driven fluid 2 may be organic solution (such as silicone oil) and the surrounding fluid 3 may be air. More specifically, the main driven fluid 2 and the surrounding fluid 3 are not limited to the above descriptions, that is, the fluid of the two fluids selected by users having a higher dielectric constant is the main driven fluid 2, and the other fluid of the two selected fluids is the surrounding fluid 3.

[0040] Please refer to FIGS. 1A, 2A, 2B, and 2C. A voltage source 4 is electrically connected to the conductive layer 112 and the patterned conductive electrode 122, so that the conductive layer 112 and the patterned conductive electrode 122 define a virtual reservoir 141 and a virtual channel 142 in communication with the virtual reservoir 141. The main driven fluid 2 is arranged in the virtual reservoir 141. Said in detail, the patterned conductive electrode 122 has at least one strip-shaped electrode and at least one rectangle-shaped electrode. The conductive layer 112 and the at least one rectangle-shaped electrode define the virtual reservoir 141, and the conductive layer 112 and the at least one strip-shaped elec-

trode define the virtual channel 142. The length (L) of the strip-shaped electrode of the patterned conductive electrode 122 divided by the width (W) of the strip-shaped electrode of the patterned conductive electrode 122 is greater than 5.0. The distance (D) between the first and the second electrode plates 11, 12 divided by the width (W) of the patterned conductive electrode 122 is approximately (but not limited to) 0.5 to 2.0.

[0041] When the voltage source 4 supplies a voltage (V) between the conductive layer 112 and the patterned conductive electrode 122, the electric field generates a force (such as the dielectrophoretic force, the DEP force) that drives the main driven fluid 2 from the virtual reservoir 141 to the virtual channel 142. Thereby, the virtual channel 142 is filled fully with the main driven fluid 2. In addition, the DEP force is proportional to WV^2/D .

[0042] That is to say, when voltage of different frequencies is applied to the conductive layer 112 of the upper electrode plate 11 and the conductive electrodes 122 of the lower electrode plate 12 to generate an electric field, a force is generated between the interface of the main driven fluid 2 and the surrounding fluid 3 by dielectrophoresis. The force acts at the interface from the high dielectric constant main driven fluid 2 to the low dielectric constant surrounding fluid 3, so that the main driven fluid 2 moves along the electric field towards the surrounding fluid 3.

[0043] In detail, under the influence of the electric field, the main driven fluid 2 and the surrounding fluid 3 are electrically polarized in different degrees, so the molecules of the main driven fluid 2 and the surrounding fluid 3 tend to be aligned in the direction of the electric field. Further, if the electric field is spatially non-uniform generated by the shape of the patterned conductive electrodes 122 of the lower electrode plate 12, the electrically polarized main driven fluid 2 and surrounding fluid 3 under the influence of resultant (referred to as the DEP force) generate drift movements in different degrees, thereby the main driven fluid 2 can move in the virtual channel 142 of the planar passageway 14 without a pump. Additionally, the main driven fluid 2 may move in the virtual channel 142 of the planar passageway 14 in the form of liquid columns (as shown in FIG. 2C). Thus, the virtual channel platform 1 of the instant disclosure can be used for guiding light via the main driven fluid 2.

[0044] Furthermore, the patterned conductive electrode 122 may has a tapered electrode, so that the virtual channel 142 can be tapered, and the virtual channel 142 is full of the main driven fluid 2 (as shown in FIG. 3A). Alternatively, the patterned conductive electrode 122 may has a meander-shaped electrode, so that the virtual channel 142 can be meander-shaped, and the virtual channel 142 is full of the main driven fluid 2 (as shown in FIG. 3B). In summary, the patterned conductive electrode 122 may has at least one of the strip-shaped electrode, the rectangle-shaped electrode, the tapered electrode, and the meander-shaped electrode.

[0045] The operating frequency of the said voltage is greater than the cutoff frequency of the virtual channel platform 1. Specifically, the operating frequency of the voltage is approximately 8-12 times to the cutoff frequency of the virtual channel platform 1. For example, the cutoff frequency of such two parallel plates device (not shown) is 11.6 kHz when the distance between the parallel plates is 25 μm . However, the operating frequency of the instant disclosure is 100 kHz when D is 25 μm , which is sufficient to neglect the voltage

drop across the second dielectric layer **123** (if there is any) causing electrowetting-on-dielectric (EWOD).

[0046] Consequently, the virtual channel platform of the instant disclosure has the beneficial effects as follows:

[0047] 1. The virtual channel platform **1** of the instant disclosure has a simple structure, has no movable component and can be programmably operated and controlled.

[0048] 2. The virtual channel platform **1** of the instant disclosure may be manufactured via a simple semiconductor process (lithography process) and applies the voltage of different frequencies to the two electrode plates **11**, **12** so as to generate an electric field in order to drive the main driven fluid **2**, so that the main driven fluid **2** can move without a substantial flow channel and an outer pump.

[0049] 3. The virtual channel platform **1** of the instant disclosure does not need a close substantial flow channel, and instead of using a moving component (valve or pump) to drive the main driven fluid **2**, the virtual channel platform **1** flexibly controls and projects the conveying path of the main driven fluid **2** based on the electric field.

[0050] 4. The virtual channel platform **1** of the instant disclosure can drive the main driven fluid **2** to move in the way of liquid columns (continuous way).

[0051] 5. The virtual channel platform **1** of the instant disclosure can save sample fluid and avoid waste.

[0052] What are disclosed above are only the specification and the drawings of the preferred embodiment of the instant disclosure and it is therefore not intended that the instant disclosure be limited to the particular embodiment disclosed. It will be understood by those skilled in the art that various equivalent changes may be made depending on the specification and the drawings of the instant disclosure without departing from the scope of the instant disclosure.

What is claimed is:

1. A virtual channel platform, comprising:
 - a first and a second electrode plates spaced for forming an electric field, the first electrode plate having a first substrate and a conductive layer disposed on the first substrate, the second electrode plate having a second substrate and a patterned conductive electrode disposed on the second substrate, wherein the conductive layer and the patterned conductive electrode define a virtual reservoir and a virtual channel in communication with the virtual reservoir;
 - a voltage source electrically connected to the conductive layer and the patterned conductive electrode; and
 - a main driven fluid and a surrounding fluid arranged between in the first and the second electrode plates, wherein the surrounding fluid is immiscible with the main driven fluid, and the main driven fluid is arranged in the virtual reservoir;
 wherein when the voltage source provides a voltage between the conductive layer and the patterned conductive electrode, the electric field generates a force in driving the main driven fluid from the virtual reservoir to the virtual channel, allowing the virtual channel to be filled with the main driven fluid fully.
2. The virtual channel platform as claimed in claim 1, wherein the patterned conductive electrode has at least one of a strip-shaped electrode, a rectangle-shaped electrode, a tapered electrode, and a meander-shaped electrode.
3. The virtual channel platform as claimed in claim 1, wherein the patterned conductive electrode has at least one

strip-shaped electrode, and the conductive layer and the at least one strip-shaped electrode define the virtual channel.

4. The virtual channel platform as claimed in claim 3, wherein the length of the strip-shaped electrode divided by the width of the strip-shaped electrode is greater than 5.0.

5. The virtual channel platform as claimed in claim 1, wherein the patterned conductive electrode has at least one rectangle-shaped electrode, and the conductive layer and the rectangle-shaped electrode define the virtual reservoir.

6. The virtual channel platform as claimed in claim 1, wherein the operating frequency of the voltage is greater than the cutoff frequency of the virtual channel platform.

7. The virtual channel platform as claimed in claim 1, wherein a dielectric constant of the main driven fluid is greater than that of the surrounding fluid.

8. The virtual channel platform as claimed in claim 1, wherein the main driven fluid is an aqueous solution and the surrounding fluid is an air.

9. The virtual channel platform as claimed in claim 1, wherein the main driven fluid is an aqueous solution and the surrounding fluid is an organic solution.

10. The virtual channel platform as claimed in claim 1, wherein the main driven fluid is an organic solution and the surrounding fluid is an air.

11. The virtual channel platform as claimed in claim 1, wherein the first electrode plate has a first hydrophobic layer coated on the conductive layer.

12. The virtual channel platform as claimed in claim 11, wherein the second electrode plate has a second hydrophobic layer.

13. The virtual channel platform as claimed in claim 11, wherein the second electrode plate has a second dielectric layer coated on the patterned conductive electrode and the second substrate.

14. The virtual channel platform as claimed in claim 11, wherein the second electrode plate has a second dielectric layer and a second hydrophobic layer, wherein the second dielectric layer is coated on the patterned conductive electrode and the second substrate, and the second hydrophobic layer is coated on the second dielectric layer.

15. The virtual channel platform as claimed in claim 1, wherein the first electrode plate has a first dielectric layer coated on the conductive layer and a first hydrophobic layer coated on the first dielectric layer.

16. The virtual channel platform as claimed in claim 15, wherein the second electrode plate has a second hydrophobic layer.

17. The virtual channel platform as claimed in claim 15, wherein the second electrode plate has a second dielectric layer coated on the patterned conductive electrode and the second substrate.

18. The virtual channel platform as claimed in claim 15, wherein the second electrode plate has a second dielectric layer and a second hydrophobic layer, wherein the second dielectric layer is coated on the patterned conductive electrode and the second substrate, and the second hydrophobic layer is coated on the second dielectric layer.

19. The virtual channel platform as claimed in claim 1, wherein the first electrode plate has a first dielectric layer coated on the conductive layer and the second electrode plate has a second dielectric layer coated on the patterned conductive electrode and the second substrate.

* * * * *