

Improved Microfluidic Device and Method

Field of Invention

The invention relates to microfluidic devices and methods of use. In particular the invention relates to the operation of such devices in instances where the fluid movement is discontinuous, or in discrete portions or columns.

Background

The merging of two liquids in a microfluidic device is often achieved by using two merging channels, which can be an effective means of mixing two continuous streams.

However it is not effective where the two fluids are discontinuous or discrete liquid columns of limited lengths. For example, if one column moves through of the Y junction before the other one reaches the junction, an air column is trapped between the two liquid columns, isolating the two columns.

Consequently, they are prevented from merging as they move downstream.

One solution may be the synchronization of movement of the two liquid columns.

Synchronization may be carried out using position or speed sensors, or by precise balance of pressures driving the liquid columns. However, in practice, such synchronization is difficult to achieve due to the fact that air in the channel network is compressible and the channel network is not completely rigid due to

the use of plastic or elastomeric tubing and channel structures. This causes a time lag in liquid movement from onset and offset of pressure. Also, pressurization devices like a syringe pump or peristaltic pump typically have a backlash to generate pressure or movement after an operation signal is generated, making the synchronization difficult. In any event, synchronization imposes high infrastructure cost and high demand in control system and equipment robustness.

According, the prior art does not describe an economic, and limited practical, solutions to stop a moving liquid column in a channel at an exact location in the channel. Switching off of the pressure source cannot cause an instantaneous stop of liquid movement due to the air compressibility, deformable channel structures and tubing used in the microfluidic system, and movement backlash of mechanical mechanism of the liquid driving devices.

Summary of Invention

In a first aspect the invention provides a microfluidic device comprising; a microfluidic channel; a vent arranged to selectively introduce or release gas from said microfluidic channel so as to selectively vary the relative position of adjacent liquid columns within said microfluidic channel.

In a second aspect the invention provides a method for varying the relative position of adjacent liquid columns within a microfluidic channel the method

comprising the steps of: providing a vent in said microfluidic channel and selectively introducing or releasing gas intermediate said liquid columns through said vent.

By adjusting the position of the liquid columns relative to each other then a range of different applications may be possible. The liquid columns may be merged or have the relative position of the liquid columns placed at a known distance. The known distance may be for aligning the liquid columns with external influences such as heat or magnetic field. Further the liquid columns may be separated for much the same reason as previously discussed.

Further still the liquid columns may be formed from a single liquid column by introducing gas into the liquid stream to separate into discrete liquid columns. This may be possible by placement of the vents at specific locations so as to very precisely divide a known portion of liquid from the single liquid column.

Thus in a third aspect, the invention provides a microfluidic device comprising a microfluidic channel and a vent in said microfluidic channel, said vent arranged to selectively introduce gas for selectively dividing a single liquid column into at least two discrete liquid columns.

It will be appreciated that the gas may be air. Alternatively the gas may be a non-reactive gas such as nitrogen or possibly a highly reactive gas for the purpose of reacting with the liquid columns.

The vent may be associated with the microfluidic channel through a range of different alternatives including integrally moulding or tapping into the channel such as drilling into the microfluidic channel.

Alternatively the microfluidic device may comprise two or more substrates with each substrate machined so as to provide a component of the overall device. For instance, a first substrate may include an open channel which when engaged with a second substrate, said second substrate may seal the microfluidic channel. The second substrate may then have apertures drilled or moulded into said substrate which correspond to the open channel of the first substrate so as to provide the vents to said microfluidic channel.

It will be appreciated that, for the purposes of this invention, a liquid column is a length of liquid within a microfluidic channel. This may include a discrete length of possibly very short length with reference to the width and length of the channel. A liquid column may also include a very long length of liquid within the channel and may for the purposes of the invention be substantially considered continuous.

To this end the microfluidic device according to the present invention may allow merging of multiple liquid columns in a single microfluidic channel. The device may also permit positioning of one or more liquid columns within the microfluidic channel. The device may further permit the metering of a single liquid column through isolating or dividing a liquid column from the single liquid column.

Brief Description of Drawings

It will be convenient to further describe the present invention with respect to the accompanying drawings that illustrate possible arrangements of the invention. Other arrangements of the invention are possible and consequently, the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

Figure 1 is an exploded view of a microfluidic device according to one embodiment of the present invention;

Figures 2A to 2C are sectional elevation views of a method according to a further embodiment of the present invention;

Figures 3A to 3D are sectional elevation views of a method according to a further embodiment of the present invention;

Figures 4A to 4C are sectional elevation views of a method according to a further embodiment of the present invention;

Figures 5A to 5D are sectional elevation views of a method according to a further embodiment of the present invention;

Figures 6A to 6C are plan views of a method according to a still further embodiment of the present invention;

Figure 7 is a graph of flow rate against channel width for a microfluidic device according to one embodiment of the present invention.

Detailed Description

Thus the present invention provides a clear advantage in the manipulation of discreet liquid columns within a microfluidic channel.

Figure 1 shows a structure adopting the key features of the present invention.

Here a microfluidic device 5 is divided into three machined or moulded substrates 10, 15, 20 which are joined to create the microfluidic device.

The first substrate 20 includes a groove 25 which forms a microfluidic channel in the finished device 5. The second substrate 15 fits onto the first substrate 20, sealing the top surface of the channel 25 and incorporating several apertures being an inlet aperture 50 and three vents 30A, B, C to facilitate the transfer of

gas to and from the channel 25. The third substrate 10 completes the device 5 and provides ports corresponding to the apertures in the second substrate 15.

To this end, an inlet port 45 in the third substrate 10 corresponds to an inlet aperture 50 in the second substrate 15 for the introduction of fluid to the channel 25. The three vents 30A, B, C correspond to conduits 40A, B, C so as to provide communication between the vent ports 35A, B, C. An outlet port 55 corresponds to an outlet aperture 60 in the second substrate 15 so as to provide an outlet for the liquid within the channel 25.

It will be appreciated that mounted to the outlet vent 35A, B, C may be valves or tubing connecting further to other devices or the atmosphere so as to operate the vents 30A, B, C.

In an example of the operation of the invention, Figures 2A, 2B and 2C show sequential steps in the positioning of a liquid column 85. Here the microfluidic device 65 has a microfluidic channel 70 with a vent 75 connecting the channel 70 to a positive or negative pressure source or atmospheric pressure.

Associated with the vent 75 is a valve 80 which is selectively operable to open and close the vent. In operation a positive pressure is applied to a liquid column to move the column along the channel 70. In this case the vent 80 is opened and so permitting the escape of gas ahead of the liquid column 85. The pressure behind the liquid column is sealed from the vent 75 by the liquid column 85 and so continues to push the liquid column along the channel 70.

Subsequently the liquid column 85 reaches and passes the vent 75 providing a path for the positive pressure to be released and so preventing further movement. The release or escape of the gas precisely positions the liquid column 85 immediately passed the vent. Accordingly placement of the vent may be designed within a microfluidic device 65 for a range of purposes including observation of the liquid column or subjecting the liquid column to an external influence such as heat. Because of the selective operability of the valve 80, the residence time of the liquid column 85 in this position is precisely controlled, as demonstrated in Figure 2C whereby the valve 80 closes and so reapplies the positive pressure to the liquid column 85 which continues to progress along the channel 70.

Figures 3A to 3D show sequential views of a further embodiment of the present invention. The intent of this embodiment is to merge two isolated liquid columns 115, 120 within a microfluidic channel 100. Thus a microfluidic device 95 includes a vent 105 having a selectively operable valve 110.

As before, a positive pressure 125 is applied to the microfluidic channel 100 so as to drive two liquid columns 115, 120 along the channel. In this case, the liquid columns 115, 120 are separated by an air gap 130 which prevents merging of the two liquid columns.

As shown in Figure 3A, the valve 110 is opened and thus the gas preceding the first liquid column 115 is released through the vent 105. This continues to Figure 3B until the first liquid column 115 reaches a position immediately passed the vent 105 at which stage the air trapped within the air gap 130 is permitted to escape 135.

This permits the second liquid column 120 to progress along the channel 100 and so move relative to the first liquid column 115 as it continues to be driven by the positive pressure 125. Eventually, as shown in Figure 3C, the second liquid column contacts the first liquid column whereupon the liquid columns merge at the position immediately passed the vent 105. At this point the positive pressure is able to escape 140 through the vent and so bringing the merged liquid column to a stop. As shown in Figure 3D, the valve 110 is then closed and so reinstating the positive pressure 125 which now drives the merged liquid column 142 along the microfluidic channel 100.

Figures 4A to 4C show a similar application whereby a microfluidic device 145 includes a microfluidic channel 150 with a vent 165 operated on by a valve 166.

In this case the first liquid column 160 is positioned to receive the second liquid column 155 which is driven by a positive pressure 170. Figure 4B shows the merged liquid column 175 as the positive pressure escapes 180 through the open valve 166. Finally Figure 4C shows the closing of the valve 166 and so

reinstating the positive pressure 170 to drive the merged liquid column along the microfluidic channel 150.

Figures 5A to 5D show a still further embodiment of the present invention whereby a microfluidic device 185 is arranged to precisely position a plurality of liquid columns within the microfluidic channel 190. To this end three vents 195, 205, 215 are positioned in spaced relation to each other based upon the desired spacing of the liquid columns 225, 230, 235.

Thus the three liquid columns 225, 230, 235 travel along the microfluidic channel 190 under positive pressure 250. The liquid columns are separated by two air gaps, 240, 245 which are of a size that is not desired. The microfluidic device 185 is designed to adjust the air gap so as to correspond to the desired spacing for a range of different applications.

The sequence begins by closing the third valve 200 and the second valve 210 and so positioning the first liquid column 225 immediately passed the first vent 215. As air is released from the gap 215, the second and third liquid columns 230, 235 continue down the microfluidic channel. Figure 5C then shows the opening of the second valve 210 which stops the second liquid column and allows the release 260 of gas from the second air gap. As the second liquid column is now stationary, it no longer matters whether the first valve 220 is open or closed as the spacing between the first and second liquid columns 225, 230 will remain constant.

Finally Figure 5D shows the effect of opening the third valve 200 and so positioning the third liquid column immediately passed the third vent 195.

Thus it can be seen by selectively opening and closing the valves, the three liquid columns can be precisely placed. To maintain the air gap and progress the liquid columns down the microfluidic channel is only necessary to simultaneously close the three valves and so re-engage the positive pressure 250.

Figures 6A, 6B and 6C show a still further application of the present invention. Here the microfluidic device 270 is designed to divide a liquid column 290 into two precisely measured liquid columns 325, 330.

The microfluidic device 270 includes a microfluidic channel 275 having an inlet 276, a first outlet 305 and a second outlet 300. A positive pressure 310 is selectively applied to the channel 275.

In this instance, the channel 275 has a vent 280 which is connected to a positive pressure valve 285 capable of introducing a positive pressure to the channel 275.

As shown in Figures 6A to 6C, a liquid column 290 is introduced into the channel 275 through the inlet 276. When a precise amount of the liquid extends

beyond the vent 280, the positive pressure 310 is stopped and the inlet 276 closed. This stops the liquid column 290. A positive pressure 315 is then applied through the vent 280 which separates the liquid column into two distinct and discrete liquid columns 325, 330. In this instance the first outlet 305 is closed. Consequently the first liquid column 330 travels into the outlet channel 295 whereupon the outlet valve 300 is closed.

The first outlet 305 is opened and the positive pressure 310 reapplied with the vent valve 285 closed and so the second liquid column 325 continues along the microfluidic channel 275 towards the output 305. Thus by manipulation of the input and output valves for the microfluidic device 270, the original column is precisely divided into two liquid columns.

Further embodiments of the present invention lead to certain design criteria which may assist in the manufacture of microfluidic devices using the present invention. For instance, it will be seen in Figure 6A to 6C that the width of the air vent opening 281 may be larger than the width 277 of the channel 275 which may avoid the formation of a liquid film after the liquid columns pass the air vent. The liquid film formation may not be desirable as it may close the air vent which may cause the liquid column being pushed forward instead of maintaining its position as shown in Figure 6B.

Further the length 282 of the air vent 280 should ideally be as large as possible again to avoid the formation of a liquid film.

Similarly the length 282 and width 281 of the air vent may be as large as possible to avoid the liquid column being pushed into the air vent and consequently, leak from the main channel 275.

Further the length 282 of the air vent should be smaller than the length 283 of the liquid column.

Further still, the velocity of the liquid column may be limited so as to not push the column out of the air vent. In certain embodiments the velocity may depend upon the width of the air vent as well as the length of the liquid column as shown in the graph of Figure 7 where velocity is represented as flow rate against width of the air vent for three lengths of the liquid column of 1.5mm, 3mm and 4.5mm.

Claims:

1. A microfluidic device comprising;
a microfluidic channel;
a vent arranged to selectively introduce or release gas from said microfluidic channel so as to selectively vary the relative position of adjacent liquid columns within said microfluidic channel.
2. The microfluidic device according to claim 1 wherein the vent is a first vent and further including a second vent.
3. The microfluidic device according to claim 2 further including a third vent.
4. The microfluidic device according to claim 2 or 3 wherein adjacent vents are in known spaced relation.
5. The microfluidic device according to any one of claims 2 to 4 wherein each vent is associated with a valve arranged to provide the selective introduction or release of gas.
6. The microfluidic device according to claim 5 wherein said valve is distal from the associated vent.

7. The microfluidic device according to any one of the preceding claims wherein the vent is connected to a positive pressure source so as to introduce gas.
8. The microfluidic device according to any one of claims 1 to 6 wherein the vent is connected to a negative pressure source for the release of gas.
9. The microfluidic device according to any one of claims 1 to 6 wherein the vent is connected to ambient atmosphere for the release of gas.
10. The microfluidic device according to any one of the preceding claims further including an outlet connected to said microfluidic channel for the release of said liquid columns.
11. The microfluidic device according to claim 10 wherein the outlet is a first outlet and further including a second outlet such that the two outlets release different liquid columns.
12. A method for varying the relative position of adjacent liquid columns within a microfluidic channel the method comprising the steps of:
providing a vent in said microfluidic channel and selectively introducing or releasing gas intermediate said liquid columns through said vent.

13. The method according to claim 12 wherein the varying step includes the step of merging said liquid columns through the release of gas intermediate said liquid columns until said liquid columns are in contact.
14. The method according to claim 12 wherein the varying step includes the step of diverging said liquid columns through the introduction of gas intermediate said liquid columns.
15. The method according to claim 12 further including the step of metering a single liquid column through introducing a gas into said liquid column so as to separate the single liquid column into two liquid columns.
16. The method according to claim 12 wherein the vent is a first vent and the providing step further includes providing a second and third vent, said vents arranged to selectively open or seal said microfluidic channel, the method further including the steps of:
sealing the second and third vents and opening the first vent until a first liquid column is passed the first vent, and then:
releasing gas intermediate the first liquid column and a second liquid column then;
opening the second vent until said second liquid column is passed the second vent and releasing gas intermediate the second liquid column and a third liquid column, then;

opening the third vent until said third liquid column is passed said third vent.

17. The method according to claim 12 further including the steps of:
 - providing a first outlet and a second outlet in the microfluidic channel;
 - providing a single liquid column in the microfluidic channel;
 - progressing the single liquid column until a predetermined portion of the single liquid column has passed the vent;
 - introducing gas into the microfluidic channel so as to separate the single liquid column into a first liquid column downstream from a second liquid column, said liquid columns separated by an air gap introduced from the vent;
 - maintaining the second liquid column stationary;
 - progressing the first liquid column toward the first outlet through
 - maintaining the introduction of gas to the microfluidic channel;
 - stopping the introduction of gas, and then progressing the second liquid column to the second outlet.