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Fundamental Performance of Compact Disc-type Microfluidic Platform

Shuai Guo, Toshihiko Imato

Department of Applied Chemistry, Graduate School of Engineering, Kyushu University, Fukuoka, 819-0395, Japan

Abstract

Compact disc (CD)-type or centrifugal microfluidic platforms lead to an increasing recognition in last decades for the potential use in various fields such as biochemical analysis and diagnostics. In a CD-type microfluidic platform, all the micro-scaled chambers and channels are integrated into a normal CD-sized device, and by rotating the device, the generated centrifugal force works as the driving force to flow the solutions loaded in the chambers through the microchannels. Various special microfluidic functions, such as pumping, valving, mixing and metering of the solutions can be realized by properly adjusting the geometry of the chambers and microchannels and the programming of the rotation of the device. In this review, we would like to introduce some specific research of the fundamental microfluidic functions on CD-type microfluidic platform.

Keywords CD-type microfluidic platform, centrifugal microfluidics, pumping, valving, mixing, metering

1. Introduction

The development of microfluidic technologies over the last decades has been vigorously accelerated by the prospects of process integration, miniaturization and parallelization in life sciences, especially for biochemical and biomedical analysis. Until now some key laboratorial microfluidic functions such as sample injection, separation, metering, mixing, reaction and detection have been successfully demonstrated by separated stand-alone microfluidic devices. A new conception of microfluidic device as compact disc-type or centrifugal microfluidic platform was advanced in last decades [1-5], and several commercial products have been launched to the market [6-9]. Several of the applications are well competitive or even far superior to conventional technologies. Crucial advantages of the device are the decreased consumption of sample and reagent solutions, the reduced system size as well as a rapid time-to-result.

In this review, we wish to introduce essential microfluidic functions on CD-type microfluidic platforms, such as a pumping function [16-21], which is the representative advantage of CD-type microfluidic platform. Compared with other technologies, such as a mechanical pump (hard to miniaturize and integrate), an electro-osmosis pump (high electric field is needed and limit for biomolecular samples) and a thermal pump (not entirely developed due to the high heat exchange rate in microchannels), centrifugal force, which results from rotation, is proper for fluid transportation, as it is simple and no additional component is needed. Some other microfluidic functions such as valving [24-28], mixing [31-35] and metering [36-39] are also necessary and important for the application of the CD-type microfluidic platform to biochemical and clinical analysis, and will be introduced in this review.

2. Fabrication

There are mainly two methods for fabricating the microfluidic devices such as CD-type microfluidic platforms. One conventional method is computerized numerically controlled (CNC) machining [10, 11], in which end mills are used to curve a substrate made of poly(methyl methacrylate) (PMMA) etc. Designs of microfluidic devices are prepared in an AutoCAD or similar software, and uploaded as files to the program of a milling machine. The designs are then machined in a PMMA platform by using end mills ranging in diameter from 125 μm to 1.59 mm [10]. By using this method, the design on PMMA surface is concave and for further using, in some cases, a negative poly(dimethylsiloxane) (PDMS) replica needs to be prepared. First the machined parts are replicated in PDMS by casting its prepolymer, and then this negative replica in PDMS is oxidized in oxygen plasma and exposed to the fluorinated silane to form a surface with low adhesion of PDMS. Finally PDMS was cast against the negative replica to form the needed microfluidic devices.

The disadvantage of the CNC machining method is the lack of a smooth surface [11], usually the surface roughness is around μm level. And it is hard to fabricate a channel with a high aspect ratio (height to width ratio), which is limited to less than 2. Also the method results in bad dimension control, with a device often 10% larger than design. While this CNC machining method also holds the advantages with no material limitations, and various metals, glass and plastic can all be used. Also it is suitable to prepare microfluidic devices with microchannels of different depth.

Another method for fabrication of microfluidic devices is photolithography, which has already been widely used in micromachining [12, 13]. It has several advantages compared with the CNC machining method. For example, a high aspect ratio features are attainable and very small feature sizes (~ 1 μm) can be achieved. While in the CNC machining method, the size is limited to be larger than 50 μm. The procedure of the photolithographic method is mainly as follows. A fluidic structure is first designed in an AutoCAD or a similar program and then converted into a photomask. The material of the photomask affects much in the microfluidic device quality. A silicon wafer of 120 mm in diameter is used as the substrate, and is coated with a negative photoresist. After baking, the wafer is exposed under UV light with the photomask, and then the photoresist is developed in propylene glycol methyl ether acetate (PGMEA). A 10:1 mixture of PDMS oligomer and cross-linking agent is poured onto the mold, and after baking, the designed PDMS microfluidic device is prepared.

The quality of the photomask affects much on the smoothness of the wall surfaces of the microchannel in the photolithographic method. Lee *et al.* [11] compared two negative photoresist (SU-8) films on silicon substrate made by different UV-photolithographic methods. One is developed by using a chrome-coated photomask, and another is developed by using a transparency photomask. The SEM image indicates that the microfluidic devices developed by using a chrome-coated photomask shows much better feature shape and surface smoothness, compared to that developed from a transparency photomask. However, the latter is much less expensive (a few dollars to several hundred dollars). For feature sizes larger than 20 μm, the transparency photomask is a very low-cost way for initial design and testing of microfluidic devices.

Lee *et al.* [11] also discussed different molding methods for preparing microfluidic devices, including liquid resin casting, thin wall injection molding and hot embossing. In liquid resin molding method, a replica PDMS is prepared from the "mother" silicon wafer and used for fabricating "daughter" plastic mold. Liquid resin molding has no limitation in mold inserts, and the process is simple. No expensive machine is needed and it is cost effective. But the dimensional control of the device is less than the ones prepared by an injection molding method, which uses metal molds and is especially good for small features with low aspect ratio. The dimensional control of the injection molding method is excellent, and the cost is the highest within these 3 methods. For a hot embossing method, it asks lower tooling cost than injection mold, and holds better effect for small features. Nowadays proper bonding without affecting the shape and size of microchannels is still an unsolved issue in fabricating polymer based microfluidic devices.

3. Pumping

Various technologies of pumping liquids such as a mechanical pump, an electro-osmotic pump and a thermal pump have been applied to use for microfluidic propulsion. The mechanical pump is often used for delivering liquids by applying pressure to the liquids to flow. When it is used for microfluidic devices, the mechanical pump needs to be miniaturized and integrated, which rises up the cost and complexity. The electro-osmotic pump [14] works by applying an electric field to the fluids containing electrolytes, and it needs a high electric field and depends strongly on the properties of fluids to be pumped [15], such as ion strength or pH. The use of the pump is limited for pumping biomolecular solutions. The thermal methods can also be used for microfluidics propulsion. However, since the heat exchange rate is high in microchannels, this pumping method is still in the early research stage and it requires careful control of the local temperature in the individual reservoirs.

In contrast to the above pumping methods, centrifugal force, which is resulted from rotation, is proper for flowing the fluids through the microchannel in the outward direction on a CD-type platform, with respect to simplicity and capability of fine flow control through proper design of location, dimension and geometry of channels and reservoirs in the microfluidic devices, which can be designed freely by using an AutoCAD or a similar software. Madou *et al*. [16] carried out a work for fabricating a CD-type microfluidic platform and applying several microfluidic functions on the platform, including flow sequencing by centrifugal force and capillary valve. In the research, the expression of critical rotation speed of each fluid is carried out, and a series of parameters, such as solution property and channel geometry, affect the critical rotation speed. By carefully designing the geometries and dimensions of channels and reservoirs, flow sequencing can be realized.

There are two counterforces acted on the fluid front, one is the centrifugal force and the other is the capillary force, which have the opposite directions with each other. Liu *et al*. [17] built up a theoretical model to describe the force balance between the two forces and drive an equation by using several related parameters of this process. In their research, the expressions for velocity, flow rate of a solution in reservoir and in a channel, and pressure distribution have been proposed by a 3-D model. The solution in the reservoir begins to flow just after the rotation speed reaches to the critical rotation speed and the flow velocity rapidly increases, and then rapidly decreases to a constant value within 10 ms. The flow rate depends on the cross-section area of the microchannel, the pressure gradient and the centrifugal force in the fluid. The curve of pressure distribution in radial microchannel is a parabolic distribution with a minimum value according to their theory. According to the authors, the 3-D analysis provides a more accurate prediction than that based on 2-D analysis, and is capable for design and analysis of microfluidic devices.

Besides the centrifugal force, an electric force or a magnetic force can also be integrated on a CD-type microfluidic platform to realize some special functions. Wang *et al*. [18] integrated electrodes on the CD-type microfluidic platform to generate an osmotic flow and combined it with the centrifugal force to increase the separation efficiency by using the dual-pumping method. The design is shown in Fig. 1.

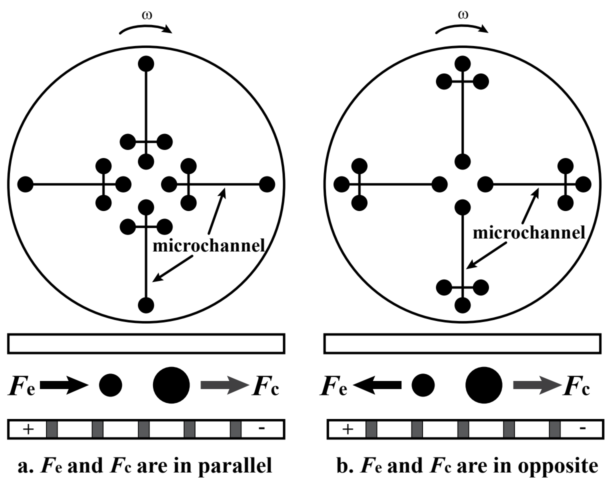

Fig. 1 Diagram of the centrifugal-electric field force dual-pumping method

As shown in Fig. 1, the fluid in the microchannel is affected by the centrifugal force and the electric field force, with the same direction or the opposite direction. The authors used this designed CD-type microfluidic platform for the separation of rhodamine B and xylene cyanole in the radial microchannels. The experimental results demonstrate that the electro-osmotic flow effect can be effectively reduced by the centrifugal force when these two forces are in the opposite direction. The advantage of this device is that the electrophoresis separation time can be prolonged and the length of microchannel can be shortened. Therefore, the separation efficiency can be improved by using such kind of the CD-type microfluidic platform.

In radial microchannels in the above mentioned microfluidic platform, the fluid is affected by the centrifugal force, the electric field force as well as the friction force induced by the Coriolis force, which exerted in perpendicular direction to the centrifugal force. At a high rotation speed, the friction force becomes extremely large and will produce Joule-heat. In order to reduce the friction force as well as the resulted Joule-heat, Wang *et al*. [19] improved their prior platform and developed a new CD-type microfluidic platform with the parabolic shaped microchannels. The electrode structure is the same as mentioned before, and the parabolic microchannels are introduced instead of straight radial microchannels. The authors carried out the theoretical calculation of the interaction within centrifugal force, electric field force and Coriolis force and simulated parabolic channels at different rotation speeds. Also the authors carried out experiments to confirm the theory. Rhodamine B and xylene cyanole were used for estimating the separation efficiency. According to the results, during applying the electric force, the sample in stationary (0 rpm) straight channel travels faster than that in the straight channel during the rotation. It implied that the molecules in the sample solutions were slowed down by the Coriolis induced friction. Further results show that samples travelled faster in a rotating parabolic channel than in a straight channel, which indicated that the friction force was reduced in the parabolic channels, as well as the reduction of Joule-heat.

In addition to the electric force, a magnetic force can also be integrated on the CD-type microfluidic platform to realize some microfluidic functions. Haeberle *et al*. [20] introduced an interesting design for gas-to-liquid sampling on the CD-type microfluidic platform by using a rotational steel and a stationary magnet. A thin PDMS lid with a thickness of roughly 0.7 mm incorporating two steel plates is placed above the two pump chambers. The platform is rotated at a frequency to pump a liquid in the reservoir through the microchannel network (starting from the in-port towards the out-port). An environment gas is pumped by the sequential displacement of the membrane into the pump chambers while passing a stationary permanent magnet. The pumping sequence includes 4 stages: (a) closing of the valve with the PDMS-membrane at the seat of the valve chamber; (b) action on the pump chamber to displace a volume of gas into the connected microchannel through the out-port; (c) after the stationary magnet passed the valve chamber, the inlet is opened again; (d) the pump chamber is refilled after the stationary magnet is passed.

The functional principle of the micropump is directly visualized by the displacement of an ink-colored liquid through a meander-shaped microchannel. The out-port is connected to the in-port through a meander-shaped channel. The stroboscopic pictures show that a static ink-colored liquid plug in the microchannel flows during rotating the platform at 5 Hz without a magnet placed along the pump orbit, and the environmental gas suck is displaced in a stepwise fashion after setting the permanent magnet at the orbit of the pump. This structure can be integrated with other downstream features to realize microfluidic functions.

Recently Samra *et al*. [21] developed a kind of a thermal-pneumatic pump (TPP) on the CD-type microfluidic platform, which could deliver a solution in the inward direction, from the chamber further from the center to the chamber closer from the center. According to the authors, a halogen lamp was used to transfer the heat energy to the surface of the platform, and the air in the ventless chamber was heat up from 295 K to 330 K. The 20 μL solution in the chamber linked with the ventless chamber was pushed inward through the microchannel into the reservoir which is closer to the center, under the rotation speed of 300 rpm. According to the authors, the generated pumping rates could be simply controlled by how well the platform absorbs IR energy, and the highest pumping rate about 17.6 μL/min was achieved. This kind of pump is based on the thermal expansion of air to move liquids, so that it has no requirement of the surface property of the platform device, and it holds a benefit that this thermo-pneumatic pump can be added to the microfluidic devices based on heat mechanisms.

4. Valving

The capability of precisely controlling a fluid on the microfluidic devices is essential. Due to the large surface-to-volume ratio of microfluidics, it is possible to use a capillary force as a valve in the microfluidics. One way to apply a capillary valve is to change the surface tensions of the fluid meniscus through electrocapillary or thermocapillary techniques [22, 23]. While the disadvantage of these techniques is that the additional components are needed, and this makes the system complicated and separated. Thus simplifying the design and fabrication process of microfluidic platform to realize a capillary valve is crucial in achieving controlling the flow of a solution in the microfluidic devices. One effective and widely used method is a sudden expansion of the microchannel which can stop the liquid meniscus [5, 10, 25]. The fluid front is stopped at the beginning of the expansion and when the centrifugal force overcomes the capillary force, the fluid moves on to flow. Thus the flow regulation by the valving technique is easily achieved by such a simple geometry of the microchannel.

The most important performance of a capillary valve is how much pressure it can withstand before bursting. Cho *et al*. [24] proposed a rigorous theoretical consideration for the capillary valve based on a 2-D model. The critical rotation speed for a solution to flow was obtained by considering the change in the contact line at the solid-liquid-air interface, and was affected by the geometry of a microchannel and the surface property. In order to confirm the theory, the experiments were carried out by different assembled wedge angles of expansion and the channel width. They showed that there was a reasonable agreement between the experimental results and the theoretical calculation.

Chen *et al*. [26] carried out experiments to improve the 2-D theory mentioned above by considering a more precise 3-D theory of the capillary valve. The analysis is based on the surface energy change at the 3-D meniscus shape in a rectangular channel at a sudden expansion. In this 3-D model, the channel depth is taken into consideration, which increases the accuracy of the theory. Similarly the critical rotation speed was determined by the channel dimension (the width and depth), the geometry (the wedge angle) as well as the surface properties (the surface tension and contact angle). Also they carried out experiments to grab fluid situations during rotation to obtain the critical rotation speeds under different situations by using CCD camera to confirm their theory. They indicated that there is a better agreement between the experimental results and the theoretical values resulted from this 3-D model by comparing with the theory in Cho's work. Both the theory and the experiment consistently show that the burst frequency is higher for the valve with a smaller channel width, a larger aspect ratio and a wider wedge angle. The 3-D theory is in good agreement with the measurements of burst frequency.

Kim *et al*. [27] developed an interesting passive flow switching valve by considering that the Coriolis force always exists in microfluidics during the rotation. The authors designed a symmetric junction where a common inlet and two outlet channels meet, with a double-layered structure, as shown in Fig. 2.

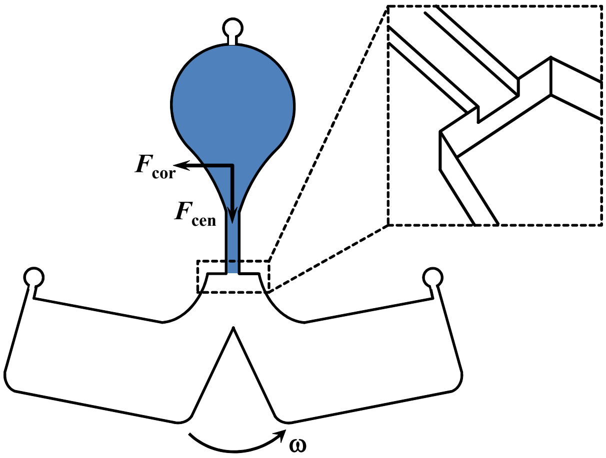

Fig. 2 Diagram of a passive flow switching valve with a double-layered structure at the junction of channels

The authors carried out the theoretical consideration of the relationship between the centrifugal force and the Coriolis force at the double-layered junction under different situations, rotating in the clockwise direction, or the counter-clockwise direction. According to the theory, the ratio of the liquid level filling a selected reservoir to the sum of filling levels in both reservoirs is affected by the junction geometry, the surface properties, as well as the rotation speed. When the rotation speed was increased to 40 rad/sec, the entire flow passing through the junction bends to a selected reservoir with about 50% rate. If the rotation speed is above 90 rad/sec, the ratio increases to 100%. The liquid was switched to a selected downstream chamber by the junction under the effect of the Coriolis force. With different rotation directions, the solution flows into the different chambers. This flow switching valve and affinity-based technique have great potential in bioassays and biomedical diagnostic applications.

Recently Faqheri *et al*. [28] developed a kind of a vacuum/compression valving (VCV) system using a paraffin-wax on a centrifugal microfluidic platform. A VCV was implemented by sealing the venting channel/hole with wax plugs (for normally-closed valve), or to be sealed by the wax (for normally-open valve), and was activated by localized heating on the CD device surface. According to the authors, the solution can be held in the reservoir either by the vacuum valving or the compression valving, and with the specially designed CD device in the research, which allows the melted wax from a normally-closed valve (which releases it when the wax is melted) transferring to a normally-opened valve (which seals it when the wax solidifies) by the centrifugal force. The functions of flowing switching and liquid metering sequence were estimated and compared with the theoretical study, and the results indicated that the applied VCV lowers the required rotation speed to perform the microfluidic processes with high accuracy and ease of control.

5. Mixing

In order to satisfy the widespread success of microfluidic devices, the diffusion limited speed of mixing and reaction of liquids need to be solved. Since the laminar microfluidic flow in the microchannel [10], it requires technologies to increase the diffusion speed, for instance, using chaotic advection by actuation of paramagnetic beads in an external field [29-31] has already been developed. The beads are exposed to a time-varying magnetic field which is generated by an array of current-oscillating electromagnets. Although efficient mixing can be demonstrated in these devices, the cost is high and the complexity is raised up.

Grumann *et al*. [32] developed a novel chaotic mixer by using magnetic beads in chamber on a compact disc-type microfluidic platform. Instead of using a time-varying magnetic field, the chamber was rotated in a magnetic field generated from a stationary array of permanent magnets. From the view point of the magnetic beads, a time-oscillating magnetic force is generated by the spinning through a static magnetic field. The design of the CD-type microfluidic platform is shown in Fig. 3. The design was simple. Two inlet reservoirs were linked with a mixing chamber. A set of permanent magnets was fixed in the lab-frame at radial positions which are positioned inbound and outbound relative to the mean orbit of mixing chamber. A magnetic bead in the chamber is affected by an alternating radial driving magnetic force which induces advection via the viscous drag force.

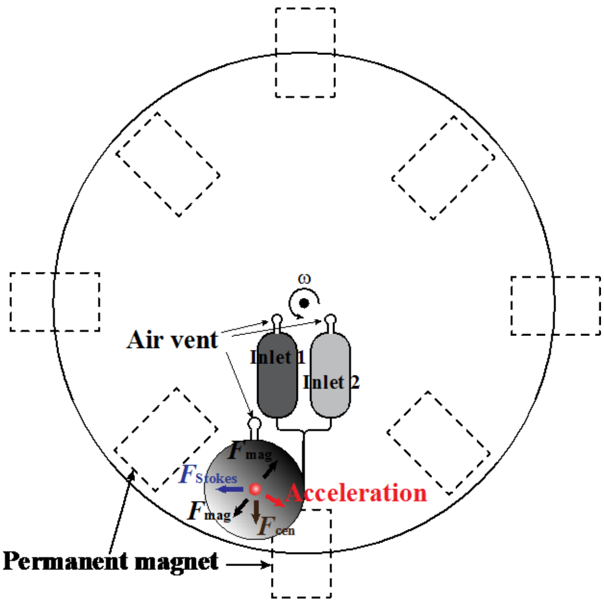

Fig. 3 Diagram of a micromixer using magnetic beads spinning in a stationary magnetic field

In such a system, the magnetic beads worked as magneto-hydrodynamic transducers, drawing energy from the rotating motion which is converted by means of the magnetic field into an increase of mixing entropy of the fluid. The authors also carried out the mixing mode without magnetic beads, while with an alternate spinning direction. Periodic changes of the sense of rotation transferred a gradient of angular momentum into arising currents within the fluid upon acceleration and deceleration. Both two modes, the magneto-hydrodynamic interaction by using magnetic beads and the liquids based on alternative accelerated and decelerated rotating, were combined and compared.

A characteristic mixing time is defined as the 1/e-decay of the standard deviation. Under the mere diffusion condition (no beads used and constant spinning) it holds the longest mixing time of 7 min. The alternate shaking mode without beads has a mixing time of 3.0 s, while the bead-based mixing in constant spinning mode has a lower mixing time of 1.3 s. When combining alternate shaking mode and bead-based mixing mode together, the mixing time is only 0.5 s, which accelerates mixing by three orders of magnitude. This structure is efficient for sample mixing and reacting as well as of low-cost and easy operation.

Haeberle *et al*. [33] explained another condition of mixing on compact disc-type microfluidic platform, which occurs in radial straight microchannel under the effect of Coriolis force. As shown in Fig. 4, two forces acted on the fluid in the straight channel, the centrifugal force and the Coriolis force. The Coriolis force induces a transversal convection u(F_{cor}), which is confined by the side walls of the channel. Once arriving at the wall, the liquid must escape from the trailing liquid, which experiences a greater Coriolis force.

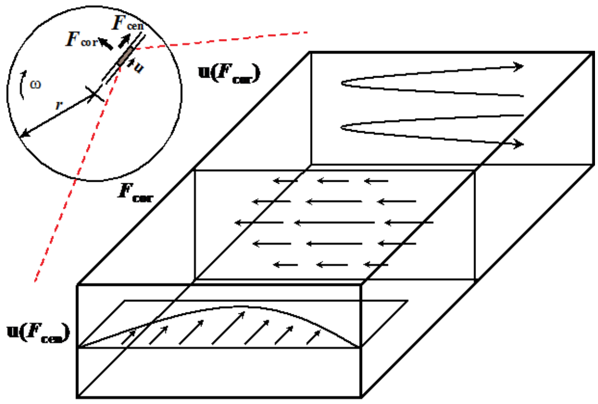

Fig. 4 Schematic diagram of the convection resulted from Coriolis force

Limited by the laminar flow in the microchannel on CD-type microfluidic platform, the diffusion time is long and the mixing efficiency is low in the straight radial microchannel mentioned above. Madou *et al*. [16] developed a cascade micromixer in order to decrease the diffusion time and increase the mixing efficiency. The design is shown in Fig. 5. In the micro-sized channels, the Reynolds number of fluid flow in the microfluidic systems is extremely small (usually less than 1). The lack of turbulent flow makes the mixing in microchannels a very challenging issue. Diffusion is the main force for mixing. To increase the mixing efficiency is generally to decrease the diffusion time, enlarge the contact area, and increase the chaotic flows. In the authors' design, two buffer solutions in reservoir 1 were released simultaneously and mixed at the joint point to create a chaotic flow. Then the mixture went through an S-shaped microchannel, which increased the contact time and created the bend-induced vortices to stir the fluid and therefore enhanced the mixing efficiency.

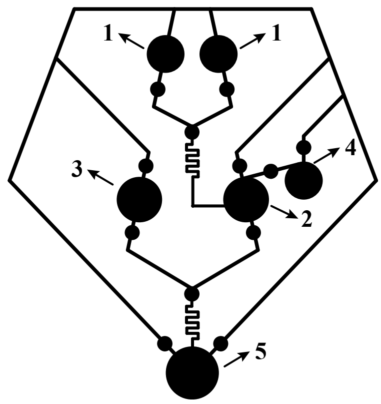

Fig. 5 A cascade micromixer design. 1, buffer solution; 2, solid protein; 3, sample with analyte; 4, overflow chamber; 5, optode

Lee *et al*. [34] carried out a more precise explanation of the structure mentioned in Fig. 5, and improved the structure by varying the cross-section of the microchannel to increase chaotic flow and vortices to enhance the mixing efficiency. The design is shown in Fig. 6.

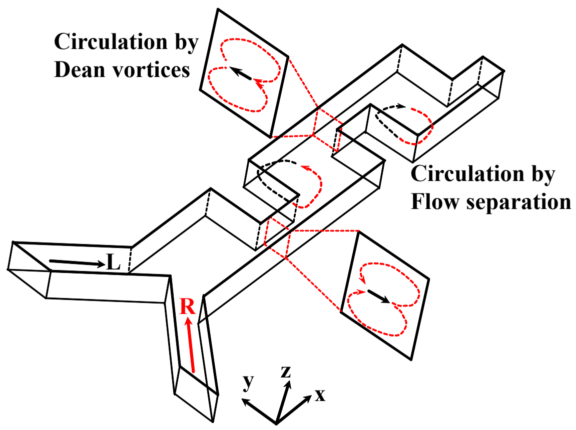

Fig. 6 Schematic of the alternately contraction-expansion microchannel for rapid mixing

As Fig. 6 shows, the channel has a width of 350 μm in the expansion channel regions and a width of 50 μm in the contraction channel regions. The entire mixing channel consists of 30 rectangular structures and observation windows for measuring the mixing performance after every 6 rectangular structures. A fluid flowing through the contraction and expansion regions forms two kinds of vortices: expansion-vortices by the flow separation in the expansion region, and the dean-vortices which is induced by the centrifugal forces acting on a cornering fluid near the contraction region. By introducing these vortices through a contraction-expansion structure, the Reynolds number in such multivortex structure was increased to 28.6~43.0, which is the highest within the reported results. This contraction-expansion array can significantly increase the mixing efficiency and therefore improve the reaction between samples.

Recently Ren *et al*. [35] has done a comprehensive study of the parameters required for increasing the vortex offered from the top, bottom, radial and end walls of the microchamber so that effective mixing can be achieved. The numerical and experimental work indicated that more effective mixing with smaller specific mixing time attributed to higher vortices and lower viscous friction, and can be obtained from higher angular acceleration/deceleration and with large chamber (longer radial extent, taller height, and wider angular span).

6. Metering

Delivery of a series of precisely metered fluids in a controlled microchannel is of important application in microfluidic devices, and several devices have already been developed for realizing this purpose. For instance, by using a combination of a hydrophobic surface treatment and air pressure [36], a series of metered nanoliter-sized liquid drops can be realized inside the microchannel. Another method is to use a proper designed microfluidic device to draw a liquid sample from a larger reservoir to a number of smaller capillaries [37] and the excess liquid flows through an overflow channel. The capillaries containing nanoliter-sized liquid samples can be released sequentially by the counterwork between the centrifugal force and the capillary valving.

Madou *et al*. [16] developed a simple structure to form a series of droplets in the microchannels. The design is shown in Fig. 7. A constriction region is formed inside a microchannel, and when a gas bubble in the liquid-gas flow passes this constriction region, it may break up into a number of equally-spaced small bubbles. This simple mechanism can be applied for the sample metering in the microfluidic systems since the distance between two metered fluid samples is determined by the snap-off time, and the liquid sample volume depends on the channel size. Sample metering can be achieved by appropriately designing the geometry of the microchannel and the constriction.

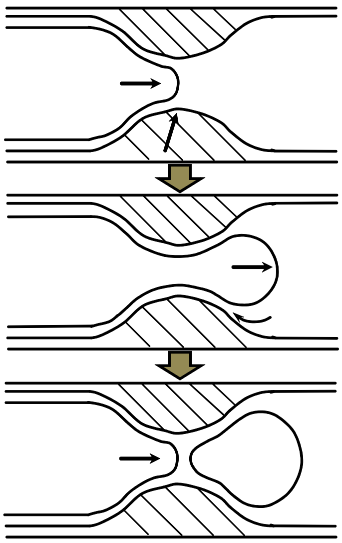

Fig. 7 Schematic diagram of a bubble snap-off structure

Andersson *et al*. [38] developed a parallel nanoliter microfluidic analysis system aimed to a high procession liquid handling based on the capillary action, the centrifugal force and the hydrophobic barriers. In the research, a defined volume of fluid (200 nL) can be metered to move through a packed column at a constant flow rate by a spin speed program, and the designed structure is a chromatography system. The loading and injection of samples and the column separation are similar to a conventional chromatography system. The functionalities shown in this work is capable for a reliable, automated and high-precision liquid handling.

Besides bubble snap-off and nanoliter fluid formation, the production and manipulation of a series of highly monodisperse water droplets is also essential within the production chain of food, cosmetics and pharmaceuticals. In this field, the size of the droplets often plays a vital role in the application. It's necessary and important to accurately control the droplet dimensions and the volume fractions within the multiphase system. Haeberle *et al*. [39] designed a junction where two kinds of fluids meet and form the droplet emulsions. The platform is shown in Fig. 8.

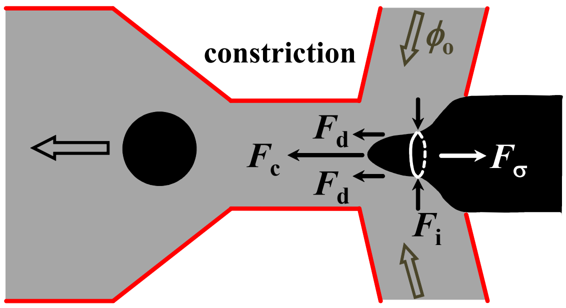

Fig. 8 Schematic diagram of the design to generate a series of monodisperse water droplets

As Fig. 8 shows, the droplet was achieved at the junction of a flow-focusing structure. The two pulling forces acting on the fluid front, including the centrifugal force F_c and the hydrodynamic drag F_d of the sheath flow, expel the water flow out of the central channel. The characteristics of the water droplets are simulated with the geometric constriction and the rotation speed, and the main characteristics, including the distribution of the droplet diameters, the spacing between the droplets, and the droplet production rate were studied. The droplet spacing is connected to the ratio between the droplet generation frequency and the flow rate within the outlet channel. And depending on the droplet size, the authors categorized the generated multiphase flows into 3 different types. First is the isolated droplets train. The diameter of the water droplets falls short of the channel height so that the droplets retain a spherical shape to minimize the surface tension. Second is the squeezed droplets train. The diameter of the droplets exceeds the channel height, and nonspherical microparticles can be produced under this situation. Third is the segmented flow, in which the diameter of the droplets is larger than both the height and the width of the microchannel. Depending on the geometry of the structure and the rotational frequency, different modes of droplets can be realized, and this structure is extremely effective for the biomedical diagnostic application on the microfluidic devices.

7. Conclusion

In this review, we introduce a novel, integrated and miniaturized microfluidic device, compact disc-type microfluidic platform. Centrifugal force works as the driving force, solely or combined with electric field force or magnetic force to realize some special functions such as mixing or metering on the CD-sized platform. Capillary force is the mostly used resistance force to control the microfluids on the platform, since it's simple in structure and no additional device is needed, which is very attractive for the biochemical detection. Different theoretical models have been built up to estimate the performance of the capillary valve. Another force acted on microfluids contributes much for mixing, the Coriolis force. Different designs of microchannels have been carried out to form more vortices to accelerate the mixing process by disturbing the laminar flow in the microchannel.

Until now, the development of compact disc-type microfluidic platform is mostly individual, and each design is unique and special, different from others. This is necessary and important for improving this device. However, it's highly respected that standard systems of compact disc-type microfluidic platform could be built up, with mature theories and technologies, to make this device a reliable analytical method for biochemistry and diagnostics, as what has been experienced for chromatography. The compact disc-type microfluidic platform holds the potential to be developed as a standard, common used analytical method in the future.

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