

Short Review on the Flow and Filtration of Polystyrene Microparticles in Micron-Scale Fluid Mechanics towards the Applications related to fluidic Microelectromechanical Systems

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Abstract

Maskless lithography, hot embossing lithography and direct bonding technique are useful to fabricate the polymethylmethacrylate (PMMA) microfluidic devices. Also, maskless lithography and indirect bonding technique are useful to fabricate the SU-8 based glass microfluidic devices. In this work, a short review on microfluidic flow and microfluidic filtration of microparticles is provided by author related to the micron-scale fluid mechanics. This review may be useful to perform the blood filtration in microfluidic lab-on-a-chip systems. Also, this review may be helpful to fabricate the nanofluidic devices and systems. Liquid-microflow is slower at higher surface-area to volume ratio inside the microchannel. The surface-to-volume ratio is generally very high inside any Nanochannel. Therefore, the Liquid-flow may be stopped before the Nanochannel. Hence, only gas-Nanoflow may happen inside the Nanochannel producing the subject of Nanofluidics. Also, this work may be useful to fabricate the fluidic microelectromechanical systems (MEMS).

Keywords: Passive capillary flow; Microchannel bend; Aqueous suspension; Separation

INTRODUCTION

Electrokinetics, electrowetting and dielectrophoresis are the popular processes of active capillary flow [1–3]. In active capillary flow, external connections may be required. In passive capillary flow, no external connection is required. Surface-driven microfluidic flow of different standard liquids is studied recently by Mukhopadhyay [4–6]. The flow features in microfluidics are required to be established to manipulate any working liquid inside the laboratory-on-a-chip systems [7].

The separation of microparticles from aqueous suspensions is studied in different lab-on-a-chip systems, for example, prototype microchannel bend, pillared microchannel bend and structurally modified microchannel bend. Straight microchannel, sudden expansion microchannel, prototype microchannel bend, and gradual expansion microchannel, are the selected designs to study the features of microfluidic flow. Nanofluidics is the next level after microfluidics in the direction of miniaturisation [8–11].

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In this short review, a brief review on surface-driven capillary flow is presented by author. Also, a brief review on microfluidic filtration is provided by author. An experimental demonstration on surface-driven microfluidic flow of dyed water is presented

corresponding to the gradual expansion microchannel. The influence of effective viscosity on surface-driven microfluidic flow of aqueous microparticle suspensions is described. Also, the effect of surface wettability on surface-driven microfluidic flow of aqueous microparticle suspensions is described. Also, this work may be useful to fabricate the fluidic microelectromechanical systems (MEMS).

BRIEF REVIEW ON MICROFLUIDIC FLOW AND FILTRATION

Effects of channel aspect ratio, surface wettability and centrifugal force on the surface-driven (passive) microfluidic flow of dyed water are studied after fabrication of polymethylmethacrylate (PMMA) based prototype microchannel bends as microfluidic devices [4]. The passive flow of dyed water is faster due to higher channel aspect ratio of rectangular microchannels [4]. The passive flow of dyed water is faster due to higher surface wettability of rectangular microchannels [4]. The passive flow of dyed water is faster due to higher centrifugal force inside the rectangular microchannels [4]. Again, in another study, the passive flow of dyed water is faster due to higher surface wettability corresponding to the gradual expansion microchannels [5].

The passive flow is slower due to higher liquid viscosity corresponding to the sudden expansion microchannels fabricated by polymers [6]. The passive flow of dyed water is faster in straight PMMA microchannels due to higher channel aspect ratio [7]. The durability of PMMA microfluidic devices is approximately six months. The diffusion coefficient of passive water flow is higher corresponding to faster flow in straight PMMA microchannels. The surface-driven microfluidic flow is slower due to higher microfluidic friction inside the microchannels. The passive capillary flow of aqueous microparticle suspension is slower due to higher effective viscosity of test suspension corresponding to the prototype microchannel bends.

The passive flow of aqueous microparticle suspension is faster due to lower effective viscosity corresponding to straight PMMA microchannels. The passive flow of aqueous microparticle suspension is faster due to higher surface wettability corresponding to straight PMMA microchannels. The passive flow of aqueous microparticle suspension is faster due to lower effective viscosity corresponding to sudden expansion PMMA microchannels.

The passive flow of aqueous microparticle suspension is faster due to higher surface wettability corresponding to sudden expansion PMMA microchannels. The passive capillary flow of aqueous isopropyl alcohol (IPA) is faster due to higher channel aspect ratio corresponding to the sudden expansion PMMA microchannels. The passive capillary flow of working liquids is faster due to lower liquid viscosity corresponding to the gradual expansion microchannels. Surface modification techniques are useful to control the passive flow speed inside the gradual expansion microchannels due to change in surface wettability.

The separation of polystyrene microparticles from aqueous suspensions is performed inside the designed lab-on-a-chip systems. The prototype microchannel bends, pillared microchannel bends, and structurally modified microchannel bends, are used to separate the polystyrene particles from aqueous suspensions with maximum efficiency. 100% separation of 10 micron polystyrene particles from test suspension is achieved in the structurally modified microchannel bends. 98% separation of 5 micron polystyrene particles from test suspension is achieved in the structurally modified microchannel bends. 99% separation is achieved by structurally modified microchannel bends in case of aqueous suspension containing particles of both 10 micron and 5 micron diameters.

EXPERIMENTAL RESULTS AND DISCUSSION IN THIS WORK

Materials and methods in experiments

In this work, the negative photoresist SU-8 is used to prepare the SU-8 based silicon stamp using the technique of maskless lithography. Spin coating, soft baking, ultra-violet (UV) exposure, post-exposure baking, development by SU-8 developer, and hard baking are the steps in maskless lithography. This

stamp is used in hot embossing lithography for pattern transfer from stamp to polymethylmethacrylate (PMMA) substrate inside the hot embossing chamber. A set of pristine PMMA microchannels are fabricated without any plasma processing. Another set of processed PMMA microchannels are fabricated by air dielectric barrier discharge (DBD) plasma processing. The PMMA lids are sealed on PMMA microchannel structures by direct bonding technique inside the same hot embossing chamber.

Results on passive capillary flow of aqueous microparticle suspensions

Figure 1 shows the schematic diagram of gradual expansion microchannel. This PMMA microchannel is fabricated by maskless lithography, hot embossing lithography and direct bonding technique. Dyed water is prepared as working liquid to test the fabricated gradual expansion microchannel. Figure 2 shows the recorded snap-shot images corresponding to the surface-driven microfluidic flow of dyed water in gradual expansion PMMA microchannel. Figure 3 shows the schematic diagram of prototype microchannel bend. Three individual aqueous microparticle suspensions (of 10 micron polystyrene particles) are prepared with the following number densities: (a) 6×10^4 particles per mL; (b) 6×10^5 particles per mL; and (c) 6×10^6 particles per mL.

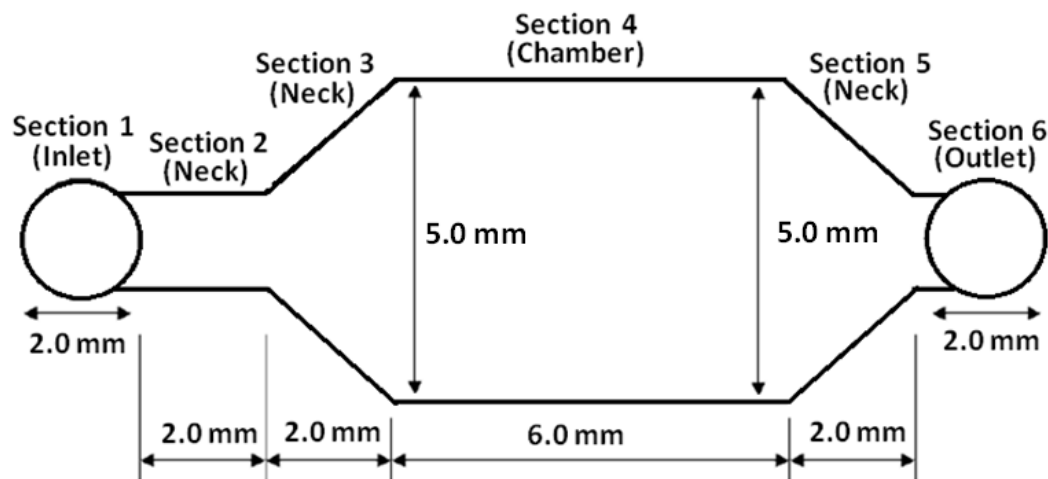


Figure 1. Schematic diagram of gradual expansion microchannel is shown (top view).

These aqueous suspensions are used to test the capillary flow characteristics in prototype microchannel bends fabricated by PMMA. The surface-driven microfluidic flow of aqueous suspension is faster due to lower effective viscosity according to the Figure 4. The surface-driven microfluidic flow of aqueous suspension is faster due to higher channel aspect ratio according to the Figure 4. The wettability on PMMA surface is made higher by the dielectric barrier discharge (DBD) plasma processing. The surface-driven microfluidic flow of aqueous suspension is faster due to higher surface wettability according to the Figure 5. Each microfluidic flow is measured corresponding to the channel 2 of prototype microchannel bends according to the Figure 4 and Figure 5.

Applications of microfluidics for the fluidic microelectromechanical systems

Luo et al have reviewed on the diamond-like carbon (DLC) based microelectromechanical systems (MEMS) to establish the scientific-connection between material-science and MEMS technology [11]. Both electronics and mechanical engineering are related to any microelectromechanical systems (MEMS). Also, suitable microfabrication technology is required for implementation of the designed MEMS devices. Principles of microfluidics may be highly required to fabricate the fluidic MEMS. Both active and passive microfluidic flow may be required to generate the electromechanical nature of any fluidic MEMS device. Hence, this present experimental work may be highly suitable to fabricate the MEMS devices. Few authors have described the features of gas microflows in detail for the applications in gas MEMS [12]. In future, gas nanoflow may be useful for nanofluidic MEMS [13–15].

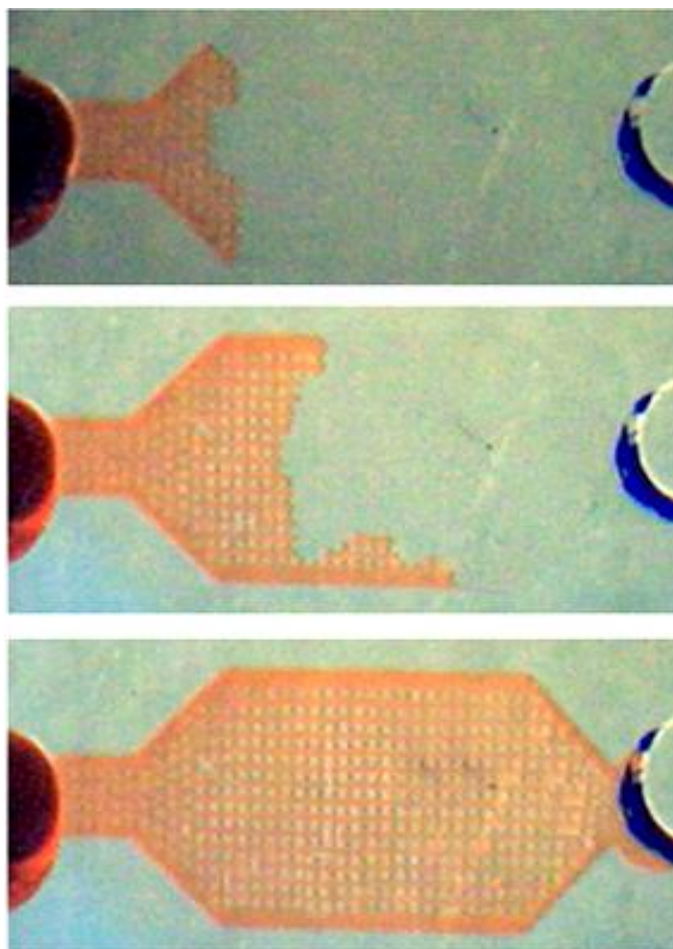


Figure 2. Recorded snap-shot images show the surface-driven microfluidic flow of dyed water in gradual expansion PMMA microchannel as fabricated by the maskless lithography, hot embossing lithography and direct bonding technique.

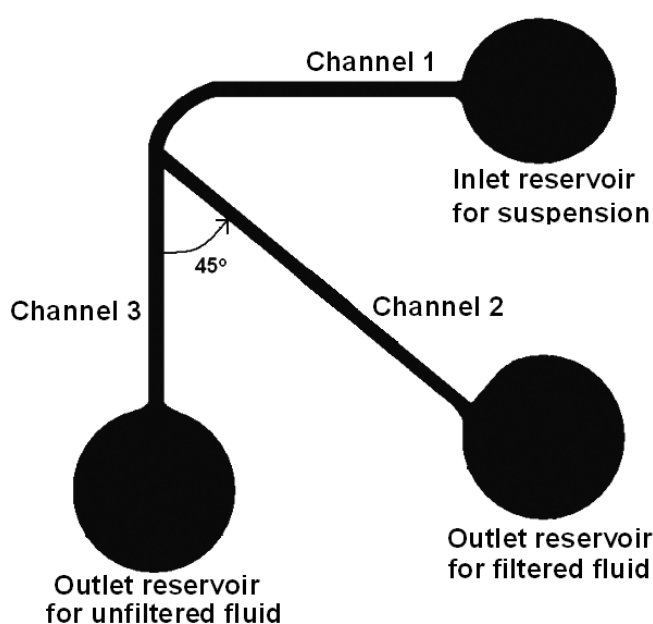


Figure 3. Schematic diagram of prototype microchannel bend is shown (top view).

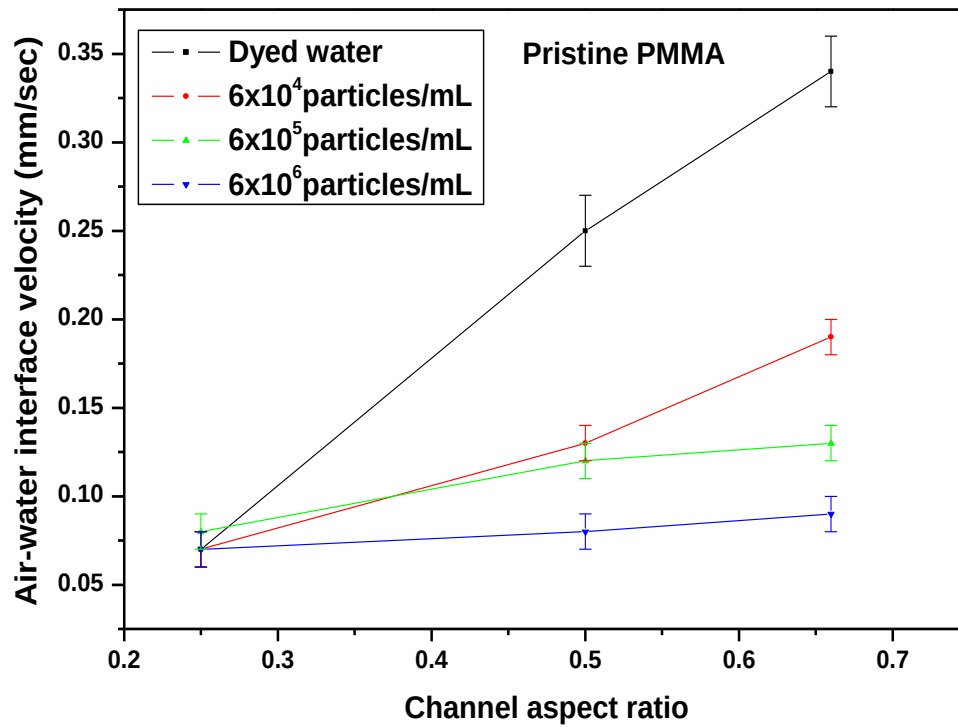


Figure 4. Variation in surface-driven capillary flow of dyed water and aqueous microparticle suspensions (of 10 micron polystyrene particles) in microchannel bends (pristine PMMA) at separation angle of 45° is shown. Each flow is measured corresponding to the channel 2 of fabricated bends.

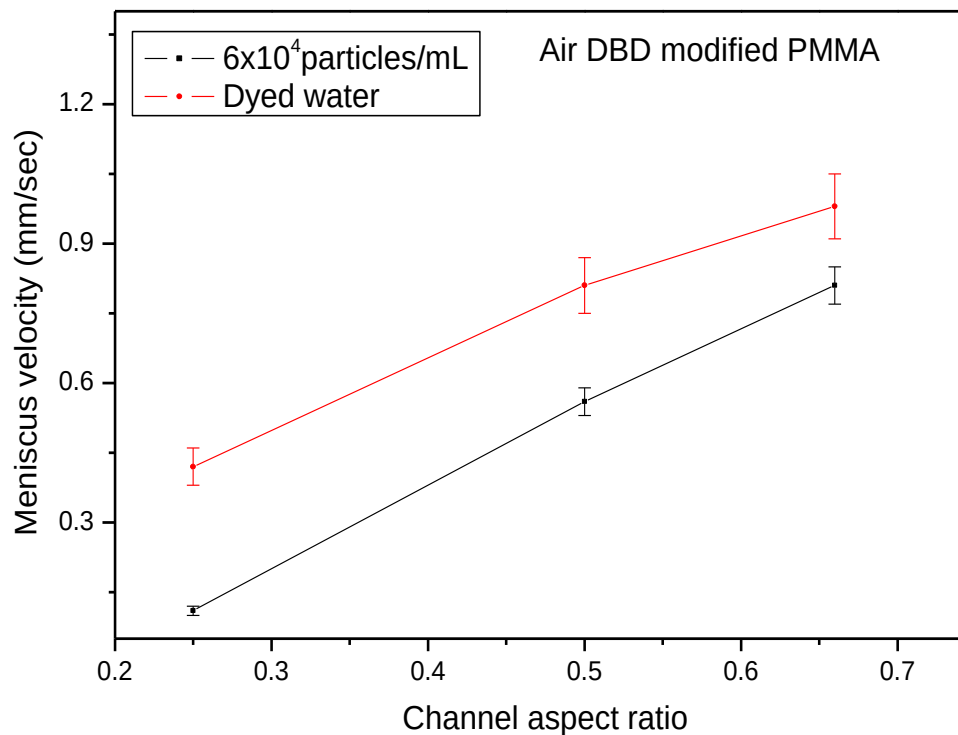


Figure 5. Variation in surface-driven capillary flow of dyed water and aqueous microparticle suspension (of 10 micron polystyrene particles) in microchannel bends (air DBD plasma processed PMMA) is shown. Each flow is measured corresponding to the channel 2 of fabricated bends.

CONCLUSIONS

According to the earlier reports, maskless lithography, hot embossing lithography and direct bonding technique are useful to fabricate the polymethylmethacrylate (PMMA) microfluidic devices. Also, maskless lithography and indirect bonding technique are useful to fabricate the SU-8 based glass microfluidic devices. Author has provided a short review on microfluidic flow and microfluidic filtration of microparticles in this present work. This review may be useful for blood filtration in microfluidic laboratory-on-a-chip systems. Also, this review may be useful for fabrication of nanofluidic devices. Also, this work may be useful to fabricate the fluidic microelectromechanical systems (MEMS).

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