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Short Report to Describe the Surface-driven Microfluidic Flow in Fluid Mechanics

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Abstract

In this short report, a brief review on surface-driven microfluidic flow is provided. Also, the maskless lithography and indirect bonding technique are used to fabricate a single SU-8 based glass microfluidic device. Dyed ethylene glycol is prepared as working liquid to test the fabricated device. The surface-driven microfluidic flow of dyed ethylene glycol is recorded by a CMOS camera catching 25 frames per second with a corresponding time-scale resolution of 0.04 second. This short report may be useful in future to control the working liquid inside the microfluidic lab-on-a-chip system. 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. Hence, this short report may be useful in future to control the working gas inside the nanofluidic lab-on-a-chip system.

Keywords: SU-8; Maskless lithography; Indirect bonding; Capillary flow

INTRODUCTION

According to Pati, the major topics of fluid mechanics are as follows: properties of fluids; pressure and its measurement; hydrostatic forces on surfaces; buoyancy and floatation; kinematics of fluid flow; dynamics of inviscid flows; flow through orifices and mouthpieces; flow over notches and weirs; dimensional and model analysis; flow of ideal fluids; dynamics of viscous flows; turbulent flow; flow through pipes; boundary layer theory; fluid flow around submerged bodies; compressible flow; flow in open channels; impact of jets and jet propulsions; hydraulic turbines; centrifugal pump; reciprocating pump; and hydraulic machines [1].

According to Cimbala and Cengel, the fundamental principles of fluid mechanics are as follows: pressure and fluid statics; fluid kinematics; mass, Bernoulli, and energy equations; momentum analysis of flow systems; dimensional analysis and modelling; flow in pipes; differential analysis of fluid flow; drag and lift; and turbomachinery [2]. According to Pritchard and Leylegian, the primary principles of fluid mechanics are as follows: fluid statics; basic equations in the integral form for a control volume; differential analysis of fluid motion; incompressible inviscid flow; dimensional analysis and similitude; internal incompressible viscous flow; external incompressible viscous flow; fluid machinery; flow in open channels; and introduction to compressible flow [3].

Bulk-fluidics, microfluidics and nanofluidics are the levels of fluid mechanics in the direction of miniaturisation [4]. Microfluidics is the micron-scale fluid mechanics, and nanofluidics is the nano-scale fluid mechanics. Polymeric materials,

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for example, negative photoresist SU-8 and polymethylmethacrylate (PMMA), are highly useful to fabricate the microfluidic devices [5–8]. CMOS camera catching 25 frames per second with a corresponding time-scale resolution of 0.04 second is suitable to record the surface-driven microfluidic flow governed due to thermodynamic effect [5–8].

In this short report, a brief review on surface-driven microfluidic flow is provided. Also, the experimental demonstration on surface-driven microfluidic flow of dyed ethylene glycol is provided corresponding to the SU-8 based glass microfluidic device. This short report may be helpful to manipulate the working liquid inside any laboratory-on-a-chip system for bioengineering applications.

BRIEF REVIEW AND EXPERIMENTAL RESULTS

Review on the Surface-driven Microfluidic Flow in Experimental Investigations

The surface-driven microfluidic flow of dyed water is faster due to higher channel aspect ratio, higher centrifugal force, higher surface wettability, and larger capillary pressure corresponding to the prototype microchannel bends [4]. These factors are useful to separate the polystyrene microparticles from aqueous suspension using the structurally modified microchannel bend with maximum separation efficiency of 100% [4]. Surface wettability, surface energy components, surface chemistry and surface topography are the factors to control the surface-driven microfluidic flow of dyed water corresponding to the gradual expansion microchannels [5]. Flow speed is higher corresponding to higher surface wettability inside the gradual expansion microchannels [5].

The surface-driven microfluidic flow of working liquid is faster due to higher channel aspect ratio, higher surface wettability and lower liquid viscosity corresponding to the sudden expansion microchannels [6]. Filling time of dyed ethanol is higher due to higher microfluidic friction inside the gradual expansion microchannels [7]. Extensive hydrophobic recovery test is performed using different aqueous working liquids to determine the durability of polymethylmethacrylate (PMMA) based microfluidic devices as approximately six months continuously [8]. The surface-driven microfluidic flow of dyed water is faster due to higher channel aspect ratio and higher surface wettability corresponding to the straight PMMA microchannels.

The surface-driven microfluidic flow is governed due to the thermodynamic reason. The kinetic energy of working liquid in surface-driven microfluidic flow is supplied by the internal energy of microfluidic device reducing the device temperature. The surface-driven microfluidic flow of aqueous microparticle suspension is faster due to higher channel aspect ratio, higher surface wettability and lower effective viscosity corresponding to the straight PMMA microchannels. The surface-driven microfluidic flow of aqueous microparticle suspension is faster due to higher channel aspect ratio, higher surface wettability and lower effective viscosity corresponding to the sudden expansion PMMA microchannels.

The surface-driven microfluidic flow of aqueous working liquid, for example, aqueous isopropyl alcohol (IPA), is faster due to higher channel aspect ratio and higher surface wettability. Each surface-driven microfluidic flow is recorded by a CMOS camera catching 25 frames per second with a corresponding time-scale resolution of 0.04 second. Surface-driven microfluidic flow of working liquid is faster due to higher surface wettability, lower liquid viscosity, lower microfluidic friction, and lower surface area to volume ratio. Water, aqueous ethanol, and aqueous isopropyl alcohol (IPA) are used as dyed working liquids to investigate the effect of surface modifications on surface-driven microfluidic flow. Surface-driven microfluidic flow of aqueous working liquid is faster due to higher surface wettability, lower liquid viscosity, lower microfluidic friction, and lower surface area to volume ratio, after the surface modifications on polymer surfaces.

Experimental Results Obtained in This Present Work

A single straight microchannel of 700-micron uniform width is designed in the laboratory computer. The channel width is uniform along the channel length. The SU-8 based glass microfluidic device containing this designed microchannel is fabricated by maskless lithography and indirect bonding technique [4–8]. In the maskless lithography, the standard steps of SU-8 processing are followed like spin coating of SU-8, soft baking, ultra-violet (UV) exposure, post-exposure baking, development by SU-8 developer, and hard baking.

The glass lid is sealed on SU-8 microchannel structure substrate by indirect bonding technique. Polymethylmethacrylate (PMMA) dissolved in SU-8 developer is the liquid adhesive to be used in the indirect bonding technique. Dyed ethylene glycol is prepared as working liquid by mixing red coloured food dye with ethylene glycol [6]. CMOS camera catching 25 frames per second with a corresponding time-scale resolution of 0.04 second is used to record the surface-driven microfluidic flow of dyed ethylene glycol. Figure 1 shows the surface-driven microfluidic flow of dyed ethylene glycol in the fabricated microchannel of 700-micron channel width as uniform along entire channel length.

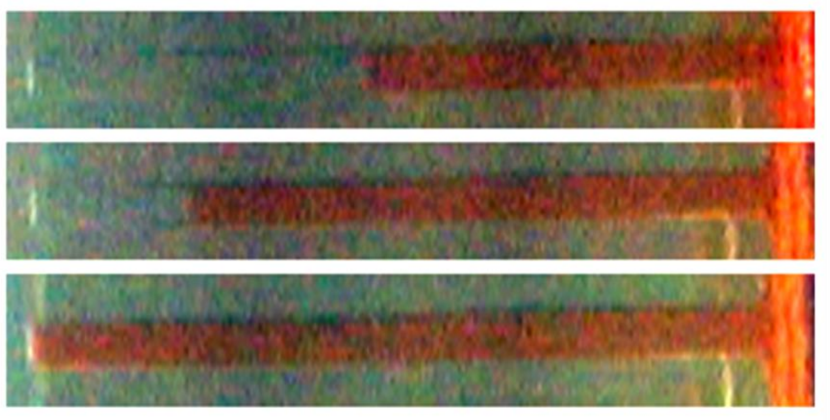

Figure 1. Snap-shot images recorded by the CMOS camera show the surface-driven microfluidic flow of dyed ethylene glycol inside the straight SU-8 based glass microchannel having uniform channel width of 700 micron along the channel length.

Specification of the CMOS Camera

FlexCam iCam Digital (CMOS camera) is useful to measure the flow characteristics in microfluidic devices. This is a CMOS camera catching 25 frames per second with a corresponding time-scale resolution of 0.04 second. The camera can record dyed ethylene glycol flow through SU-8 microfluidic devices. The meniscus velocities at different distances from the inlet can be calculated directly from the recorded video clips. This instrument has the following characteristics: (i) This is a user-friendly presentation camera, (ii) This camera features S-video and USB digital capabilities for enhanced flexibility in a wide variety, (iii) The applications of this camera are presenting objects, images, text, or microscope images in a laboratory.

In the Figure 2, the schematic of FlexCam iCam Digital is shown. The portions of the instrument are Gooseneck, Camera base, Camera head, Camera lens and lens holder. These portions are described as follows: (A) Gooseneck: The gooseneck is used to adjust the camera head or camera lens to view the object. The gooseneck must not be bent more than 90^o in any direction. Also, the gooseneck must not be tied in a knot. Nobody should attempt to repair any crack in the vinyl coating. The gooseneck should be replaced only by ClearOne; (B) Camera base: The camera base consists of power, USB and S-video connections; (C) Camera head: The camera head consists of the camera lens, lens holder, focus ring attachments, connections to gooseneck and all cables.

The gooseneck is 50.8 cm long. The weight of the instrument is 1.81 kg. The power supply is 12 VDC. The operating temperature is 0°C to 40°C. The image sensor is CMOS. The resolution is 330 TV lines (horizontal). The focus range is 6.35 mm to infinity. The lens is D-mount glass lens (8 mm).

The sensitivity is 3 lux. The S/N ratio is greater than 48 dB. Figure 3 shows the experimental set up (cross-sectional view) to record the microfluidic flow by FlexCam iCam Digital (CMOS camera). The microfluidic device is placed on the sample stage under the FlexCam iCam Digital. The microfluidic flow through the device is recorded by capturing the snapshot images by the FlexCam iCam Digital.

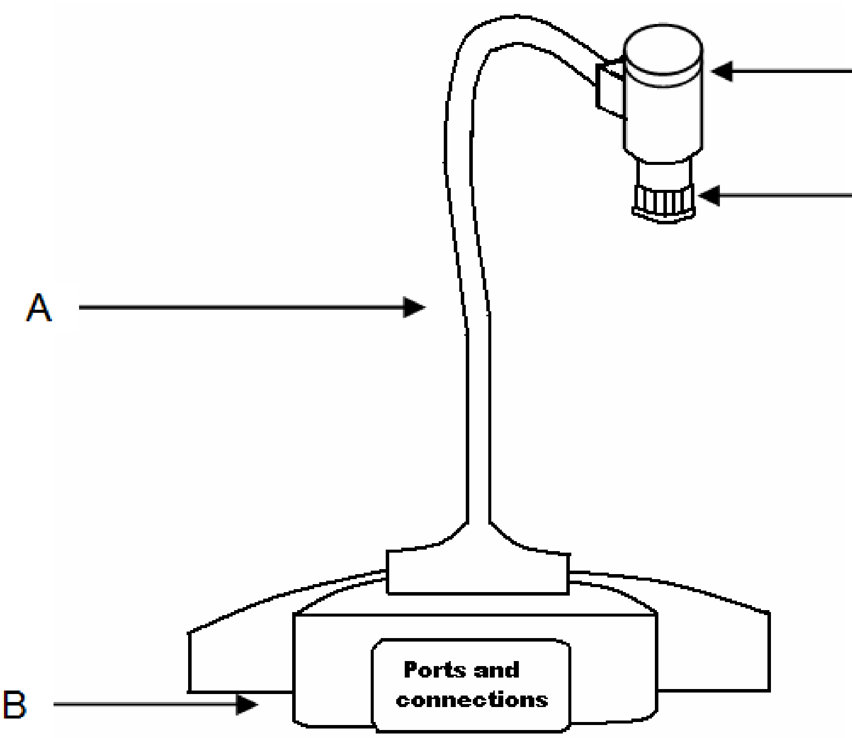

Figure 2. Schematic diagram of the FlexCam iCam Digital is shown.

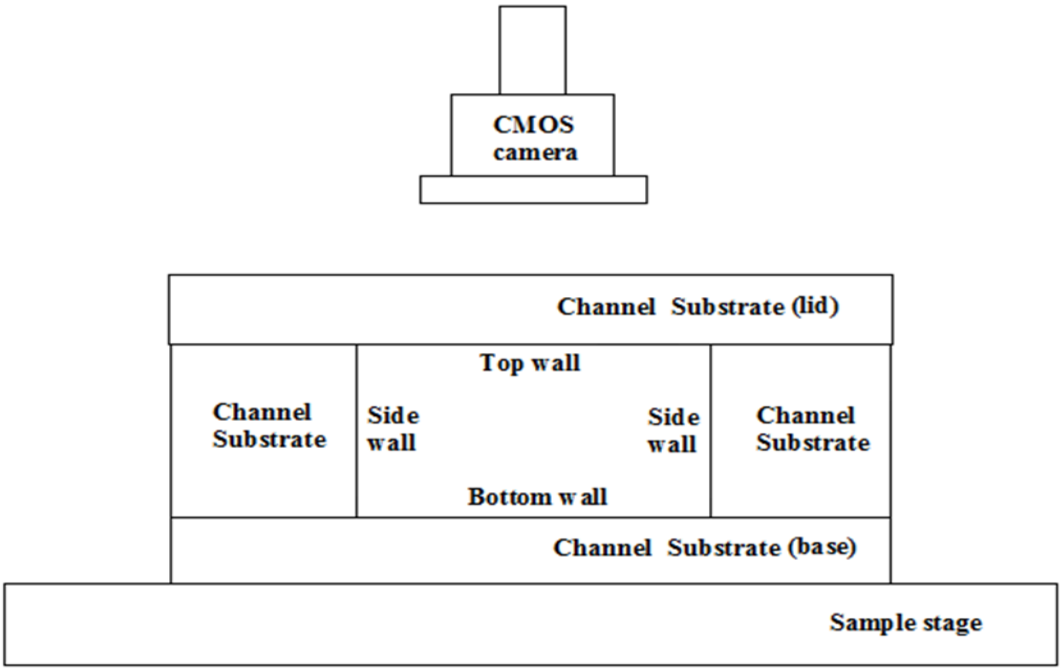

Figure 3. Experimental set up (cross-sectional view) is shown to record the surface-driven microfluidic flow using the FlexCam iCam Digital (CMOS camera). The microfluidic device is set on the sample stage under the CMOS camera.

This CMOS camera is suitable to record the liquid microflow, but this camera may not be suitable to record the gas microflow [9–13]. Hence, it is important to choose an appropriate recording-system to capture the video of gas microflow by experiments [9].

CONCLUSIONS

In this short report, author has provided a brief review on surface-driven microfluidic flow. Author has fabricated a single SU-8 based glass microfluidic device by maskless lithography and indirect bonding technique. Author has prepared the dyed ethylene glycol as working liquid to test the fabricated device. Author has recorded the surface-driven microfluidic flow of dyed ethylene glycol using a CMOS camera catching 25 frames per second with a corresponding time-scale resolution of 0.04 second. This short report authored by Mukhopadhyay may be helpful in future to control the selected working liquid inside the fabricated microfluidic lab-on-a-chip system.

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