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ORIGINAL ARTICLES

Three-Dimensional Channel Design and Fabrication in Polydimethylsiloxane (PDMS) Elastomers Using capillary Action mechanism in fluidics for life sciences

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ABSTRACT

A simple design and fabrication for a 3D microchannel that could be used as a mixer in microfluidic flow system with minimum sample available, analysis using COMSOL 3.5 Multiphysics simulation and fabricated using soft-lithography technique were done. The design is based on differential pressure drop flow using capillary effect concept which has facilitated a number of interesting flow phenomena in micro-domains. For an average pressure drop of about 100/m in the setup, flow rates of bout 0.7 to 1 µl/s were obtained. The component consists of a microchannel, two designs were tested (70, 100 microns in width) to give a continuous open circuit flow. The system was designed and fabricated for continuous flow across sensing element where there is a requirement for low residence time due to fast reaction/diffusion rates**.**

Key words: Microchannel, capillary, soft Lithography, Comsol Multiphysics, microfluidics

Intrduction

The integration of microfluidics with nano-electronic sensor for the implementation of complex reaction protocols Need Capillary that has no moving parts (Tijjani *et al*, 2012), is simple and easy to implement and thus is very attractive for low-cost Microfluidic devices is very important and There is a wide spread interest in micron-scale integrated bio-molecule analysis or synthesis systems which is referred to as lab-on-a-chip (Tijjani *et al*, 2012). A critical to this is the ability to drive a sample through the device without both moving parts and an external actuation since at the microscale level moving parts in an active mixer are very fragile. Capillarity is a force that results from the interaction of cohesion of molecules of a liquid to each other and adhesion of these molecules to the surrounding material. Possibilities of using silicon nano-wires for biological species detection are both immense and enticing. The large surface area to volume ratio of nano-wire provides high sensitivity, permitting real time label-free electrical detection. Various applications such as pH sensing detection of single viruses and identification of cancer markers have been reported, paving the interest in using nano-wires for more biological related activities (Sato *et al*, 2008). However, efficacy is restricted by detection limits which relates to the amount of bio-molecules that pass the sensor(Koch *et al*, 2010). Detection is limited if the amount of samples that interact with the sensor are lesser than required or using pomp delivery system to the microfluidic channel flaws with a lot of challenges ranging from unsuitable pressure to the chamber which could affect the detection capabilities of the transducer and the system bonding failure due high pressure injection . Hence, this validates the importance of an efficient sample delivery system. There are various considerations for designing a sample delivery system whereas efficiency of sample deliverance to the nano-wire sensors becomes the paramount concern. It aims to bring a higher efficiency permitting greater probabilities of interactions between bio-samples and nano-wire sensors. With the above scenario, we studied a thin wall, that is possible permissible distance between two parallel plate which could be use to establish smooth fluid flow using capillary effect is established by using Finite element methods through COMSOL software (Tijjani *et al*, 2012).

In recent years, research and development of micro technology and microfluidic devices have been growing exponentially that enormous novel fabrication techniques and applications have been explored and demonstrated. Because of ample fabrication techniques, there is great flexibility in selection of the appropriate substrate materials ranging from silicon and glass to polymers. Although, fabrication process of micro channels and/or micro features is the first and important step for making the desired microfluidic devices in most case. A well design technique which can offer adequate feasible result which will eliminate the resources and times waste by researchers, and preserve the fidelity of micro channel dimensions is demanded to ensure the quality and functionality of the final product. The main purpose of a lab-on-a-chip system is to handle fluids. A fluid, either a liquid or a gas, is characterized by the property that it will deform continuously and with ease under the action of external forces. A fluid does not have a preferred shape and different parts of it may be rearranged

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freely without affecting the macroscopic properties of the fluid[16]. In a fluid the presence of shear forces, however small in magnitude, will result in large changes in the relative positions of the fluid elements. In contrast, the changes in the relative positions of the atoms in a solid remain small under the action of any small external force. When applied external forces cease to act on a fluid, it will not necessarily retract to its initial shape. This property is also in contrast to a solid, which relaxes to its initial shape when no longer influenced by external forces (Park *et al*, 2009). The inter-molecular forces in a liquid are of quite intricate quantum and electric nature since each molecule is always surrounded by a number of molecules within atomic distances. Hence, when fluid is allowed to flow in its natural way without subjecting to any abnormal external force through well design medium will ease and even eliminate completely the flaws in current biochip technology and save tremendous time and cost in this evitable journey (Kuo-Kang Liu *et al*, 2010). The study begins by looking the capillary effect which is our main phenomena we are using to establish the smooth fluid delivery system through the microfluidics channel (Yue Fei *et al*, 20080).

Material and Methodology

The approach presented in this paper uses a passive microfluidic capillary-driven microchannel that exploits the capillary forces to allow fluid flows: The resulting flow is driven by a combination of forces due to gravity and capillarity, the pressure and the corresponding velocity of this flow were computed using the Navier-Stokes equations for the detailed fluid motion through the device. Due to hydrostatic forces, the pressure at the inlet is given by P = ρgH, where P is the pressure, ρ is the density of the liquid (roughly 1000 kg/m3), g is the gravitational constant (9.8 m/s), and h is the height of the liquid, for water and similar substances, $P \sim 10^4 h$, with P in Pascal and H in mm. At atmospheric pressure, $P \sim 10^5$ Pa, so H= 10 mm; If we replace the water with real sample, the effective pressure drop can be simulated since the volume of liquid that enters the channel is a negligible fraction of droplet, so that H is constant. In general, the pressure due to capillarity in a vertical cylindrical tube of radius r can be described by (equ.1):

$$P = \frac{2\gamma(\cos\theta)}{r} \quad (1)$$

Where is the surface tension between the liquid and air, θ is the contact angle (in radians, measured from the downward vertical between the liquid and wall, and r is the radius of the inlet channel. The fluid flow tend to encounter resist due to the friction between co-molecular force and adhesive force.

$$\frac{\partial P}{\partial x} = \mu \frac{\partial^2 u}{\partial y^2} \quad (2)$$

Where P is the applied pressure, x is the dimension along the length of the channel, μ is the fluid viscosity, u is the fluid particle velocity (as distinguished from the volume velocity), and y is the dimension across the channel. With no-slip boundary conditions where $\frac{\partial u}{\partial y}$ is finite so u(0) = u(h) = 0, it is easy to show that u(y) = cy(h − y), where c is a constant. The peak velocity u_{max} = u(h/2) = ch2/4, so c = $4u_{max}$/h2.

Device fabrication:

Study begins with wafer preparation which involves the scribing of wafer and cleaning. Wafer is scribed into several smaller pieces. After that, these smaller pieces of wafer are cleaned by soaking in acetone and ultrasonic. This will remove any contaminants particles on the surface. Small particles are especially difficult to remove from wafers because of the strong electrostatic forces between the particles and the substrate. Ultrasonic cleaning involves a variety of complex mechanisms, including cavitations, mechanical vibration, etc., depending on whether liquids are used in the cleaning process or not. A typical ultrasonic source is a plane surface that oscillates at a single frequency, producing a longitudinal wave. Vibration energy transmitted subsequently propagates through the fluid and Photoresist is coating onto the substrate after cleaning. SU8 is selected to create the coating layer. The SU-8 is a negative, epoxy-type, near-UV photoresist. The wafer is placed on spin coater and about 0.25cm^3 of SU8 is dropped on the wafer. A thin layer of SU8 is created on the surface of the wafer. This layer of SU8 only serves as adhesive layer of the thicker layer of SU8 layer coated later. Excessive SU8 for this layer will be wasted due to the centrifugal force during the spinning. Hence, the adhesive layer is essential in order to create thicker SU8 layer on the substrate. After creation of SU8 layer, about 2.5cm^3 of SU8 is dropped onto the substrate. The spin speed of the spin coater is set at 1000rpm for 20s with the ramp-up speed of 500rpm for 10s. The wafers with SU8 coated are soft baked at temperature of 95ºC for 25 minutes. This process helped to improve the retained solvent level. By having longer time of soft baking process, the high aspect ratio imaging can be obtained. This may cause the SU8 layer hardened and require longer time of

development. But it will result in advantages such as reducing the risk of exposed resist loss, swelling and adhesion failure, after soft baking with hot plate, the wafers are removed from hot plate and left on flat surface for cool down. This process is called relaxation. The relaxation time goes on for 15 minutes. This pre-exposure relaxation time is greatly related to sticking issue of mask with the SU8 layer on wafer. The longer the relaxation time, the SU8 layer will be more stable and less possibility that the SU8 layer will stick with the mask. Longer relaxation time will also fix the cracking problem of SU8 layer. The substrate is exposed to UV light to create pattern. The gap between mask and substrate is minimized to ensure that desired patterned is created from the design masked as shown in figure1. The exposure time is set as 55 sec. After exposure, the wafer is transferred to hot plate to complete the cross-linking, After the baking, the development follows

The substrate is placed in pure PGMEA (propylene glycol methyl ether acetate) during 5 minutes rinse with isopropanol (IPA). If white stain is observed on the substrate, the sample is soaked into the developer for another 5 minutes. This process is repeated until no more white stain can be observed on the substrate. The PDMS and curing agent is mixed according to the ratio obtained by experiment design table2. The solution is stirred slowly for 15 minutes. Improper mixing can result in a polymer that is a sticky mess. Stirring of PDMS and curing agent will create bubbles. These bubbles will degrade the optical qualities of cured PDMS so bubbles should be removed. Most of the trapped bubbles from mixing of the components will eventually rise to the top of the liquid where they may be broken by blowing across the surface. After stirring, the substrate with patterns created is placed on a plate with the cured PDMS covered. The plate is then loaded into a vacuum valve. After undergoing vacuuming process, the substrate with PDMS covered is left inside the valve for 45 minutes at 65 70 and 75□C. The vacuuming process will help to remove all the bubbles in the mixture of PDMS. The valve has to restore the atmospheric pressure slowly to avoid capsizing of the substrate. After removing the substrate from the vacuum valve, the substrate is left to cool down as shown in figure 1. The PDMS layer is softly teared from the wafer and plate. IPA can be used to soften the PDMS layer. Two adjacent pieces of PDMS is bonded together. Various test is run on the bonded PDMS delaminator.

Results and Discussion

A COMSOL Multiphysics software was used for Capillary flow experiments in a microchannel, the channel was formed by two parallel plates separated by distance H. The plate separation (H) is assumed to be precisely maintained through out the length of the channel covering a range of 8 mm to 10 mm as shown in figure2c and 3c. Experiments have been conducted using Newtonian liquids (Navier-Stokes) for model flow. Figure 2a and 3b Shows the variation of the velocity with length of the channel, the inertia point where the first time when the fluid is injected of typical runs with unstable fluid dynamics. At the inlet, are dual forces associated in driving the fluid, a gravitation force since the inlet is vertical (ρgH) and the forces due capillary, in the figure 2a, where the first point marked with pink arrow indicate the flow orientation is vertical where the velocity increases rapidly. The point shown with yellow arrow in figure2a showing distinct point where the fluid entered the channel and stabilizes for the flow, the fronts rises and stabilize and reaches the equilibrium rise height (H) at 1.28mm/s. The most interesting point is where a constant velocity is maintained through out the channel length with this velocity. A sudden upshot is experience due to the fluid leaving the channel indicate by convective flux and at the 1.3mm/s, Which is a very interesting result, to explain this, the difference in velocity between the stable state to convective influx is 0.02mm/s at least 4% higher. This indicates that all the fluids entered the channel leave the channel at the outlet without any disturbance hence, the channel will work perfectly without any clog of sample, however, in case of the second design with width 100μm show a different results though both show close trend but the good results is the previous design.

Figure2b and 3a: show the pressure drop across the lenght of channel which fluid flow, this due to capillary forces And Capillary forces result from the interaction of liquid, gas and solid surfaces, at the interface between them. In the liquid phase, molecules are held together by cohesive forces. In the bulk of the liquid, the cohesive forces between one molecule and the surrounding molecules are balanced. However, for the same molecule at the edge of the liquid, the cohesive forces with other liquid molecules are larger than the interaction with air molecules, As a result, the liquid molecules at the interface are pulled together towards the liquid, here in this experiments, and the effect of the pressure could be explained in three major points within the microchannel. At the inlet where the pressure must be greater than every point before subsequent point ahead for the fluid to start flow and in this case is greater than unity but here, the value is chosen for the purpose of explanation since the pressure used here is atmospheric pressure and this will save the purpose. The yellow arrow indicates the point at which the pressure the fluid started flowing 1.1x10E5 (Pa) and from there the pressure gradually drops to zero with constant value as the fluid flows but the design in figure 3a has not gone to zero this indicate, as the width become larger, the effect of the capillary is no longer exist.

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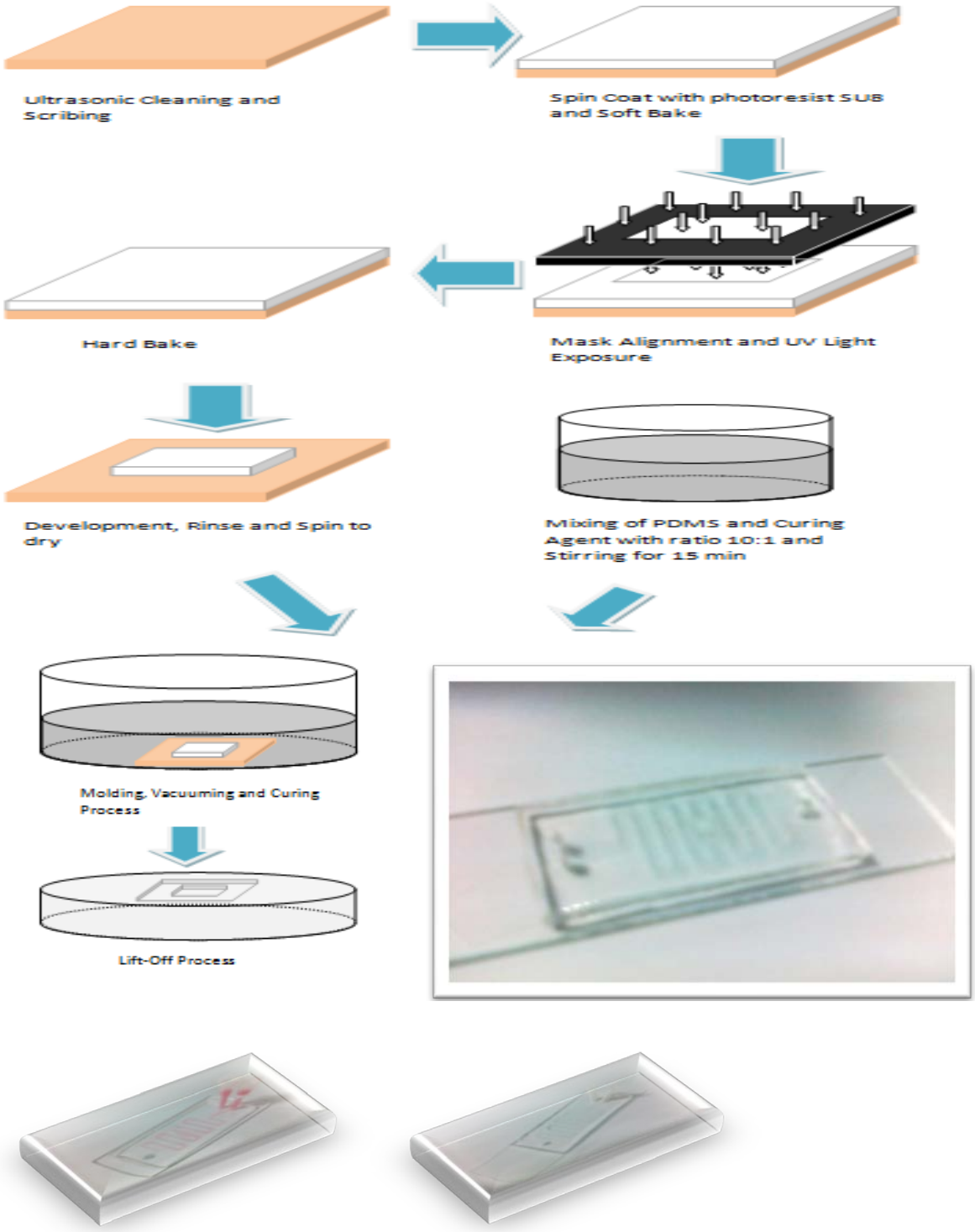

Fig. 1: shows the fabricated microchannels.

Figure3 shows the experimental result obtained during test conducted on the fabricated micro channel, Its can be seen that from figure 2band 4a, the graph differ a bit, the graph for the figure1b drop linearly but the graph for the figure 4a not a linear one but still suggest that the pressure is dropiing and likewise, the velocity curve shown little disperaty, this can be seen in figure2a and figure 4b, this might be due some error in the measurement instrument or human error.

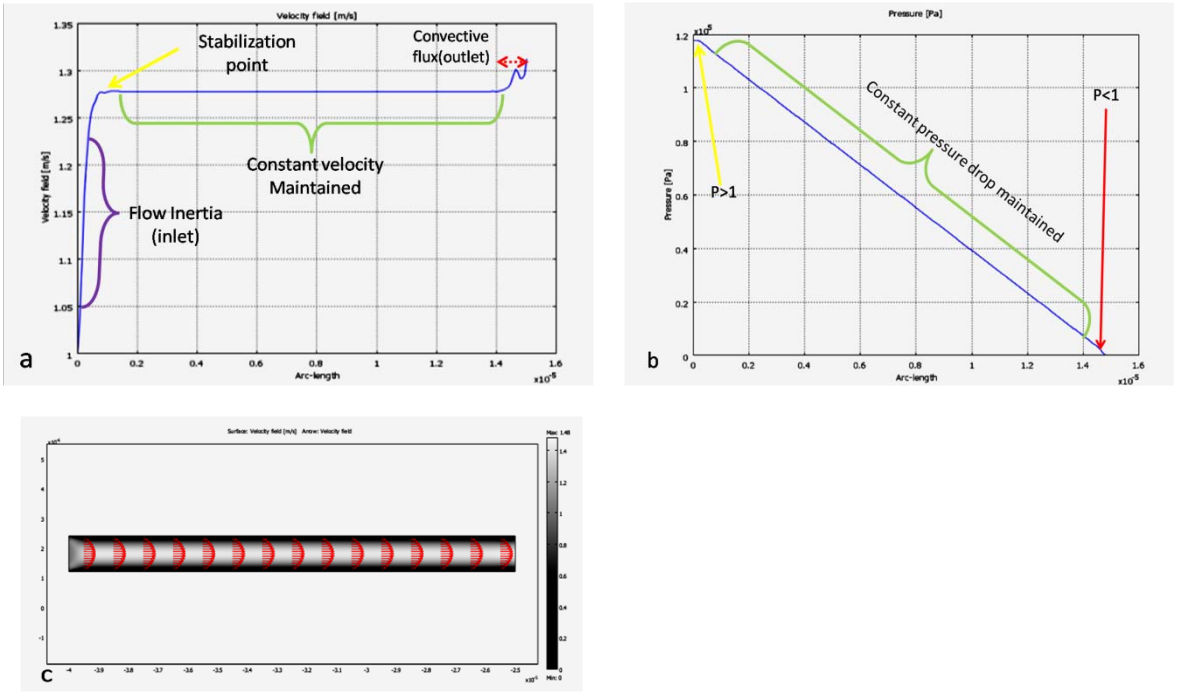

Fig. 1: (a) Graph showing a Constant velocity maintained across the microchannel (b) Showing an average pressure drop across the microchannel (c) showing 70µm width microchannel model designed with Comsol Multiphysics software

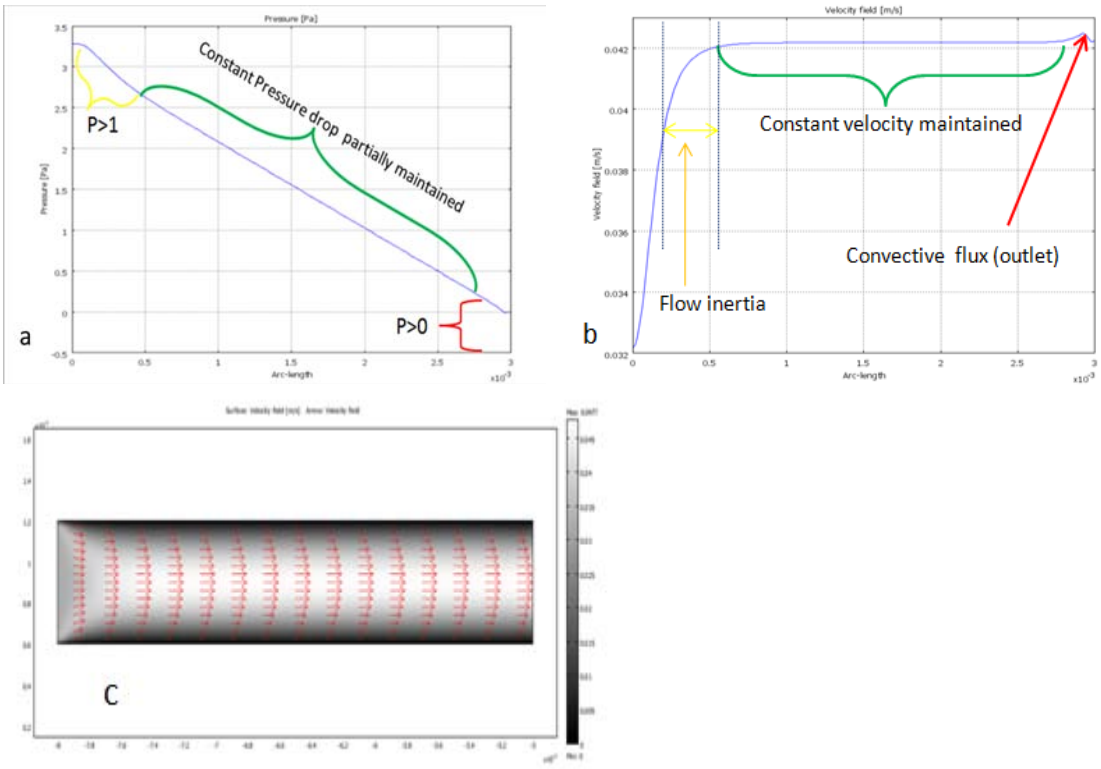

Fig. 2: (a) Showing an average pressure drop across the microchannel (b) Graph showing a partial Constant velocity maintained across the microchannel (c) showing 100µm width microchannel model designed with Comsol Multiphysics software.

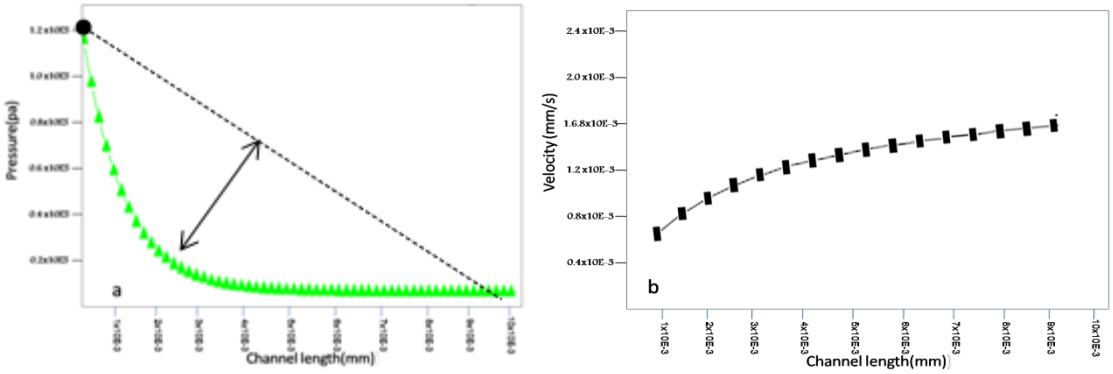

Fig. 4: Shows (a) the drop in pressure as the fluid flow through the channel (b) the velocity trend of the fluid as the fluid flows.

Conclusion:

Capillary effect for driving a fluid within microchannel have be reported. Both the numerical analysis and the experimental analysis were perfomed, each provided an inside to the flow dynamics of sample in a microchannel, when 70µm and 100µm channel were designed and fabricated, with 70µm design a uniform pressure drops and constant velocity were observed, for this reseason, this was chosen for the experimental fabrication, using this phenomena, it shown that, both approaches provided similar results with little difference.

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