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DEVELOPEMENT OF MICROCHANNEL FABRICATION TECHNIQUE AND METHOD TO INCREASE TRENCH DEPTH ON PDMS

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Abstract: **:** Integration of electronics with microfluidics devices forms a microfluidics system that provides the portability feature and enables the use of mobile application in chemical analysis, forensics, drug delivery applications etc. The performance of such microfluidic devices is shape oriented. In this paper an effort is made to develop cost effective method to fabricate different shapes of microchannel using etching and capturing replica of the micro channels on the PDMS. Different shapes of the microchannels were fabricated on PCB and there replica are molded on the PDMS. The trench depth on the PDMS was varied using electrolysis process of material deposition on the PCB.

Keywords: **Microfluidics, Microchannel, PDMS, Electrolysis.**

I. INTRODUCTION

The miniaturization as well as integration of microfluidic components is needed to form microfluidic systems. The different approaches of forming microfluidics systems for various applications has been exploited tremendously which resulted into development of various fabrication methods that led to emergence of the microfluidfic devices [1]. Micro components such as channels, valves and diaphragms in a microfluidic system can be made using different material such as elastomers, PMMA, PDMS and solution gels [2]. The micro fabrication technique used for integrating these micro components is mostly planar based patterning that further uses either photolithographic technique [3] or RF sputtering followed by the metal deposition which is further followed by lift off processes [4]. Similar to semiconductor integrated circuits, the microfluidic devices are integrated with optical or electronic components such as sensors, actuators and control logic. This integration of electronics with microfluidics devices forms a microfluidics system that provides the portability feature and enables the use of mobile application in chemical analysis, forensics, drug delivery applications etc [1]. Further, DNA amplification, its purification, separation and DNA sequencing [5] is common microfluidics application. Other microscale applications such as large scale proteomic analysis, cell sorting, profiling single cell gene expression, and memory storage development are certain latest applications of microfluidics in field of biotechnology and biomedical science [1].

Microfluidic devices are different from other devices since that these devices essentially contains either one or more channel of small dimensions nearly less than 1 mm. Microfluidic device fabrication is relatively less expensive and is focused on creating integrated portable clinical diagnostic devices for home use thereby preventing tedious laboratory analysis [1].

A. Technicalities in Microfluidics

Microfluidics provides a design efficient and optimization tool considering the numerical simulation of microfluidics essentially valuable in the microfluidic applications. The behaviour of a particular system which is initially difficult to predict can be analyzed and studied which further requires the incorporation of the complexities of different factors such as channel geometry , fluids flow rate , diffusion coefficients and possible chemical interactions altogether into a numerical model. This Numerical modelling in turn can be used to visualize the complex flow phenomenon which otherwise is difficult to obtain experimentally. The Reynolds number is an essential parameter considered in microfluidics.

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1) *Reynolds number:* Reynolds number is used to characterize the flow of the fluid through a micro channel and is defined mathematically [1] as:

$$R_e = \frac{LV_{avg}\rho}{\mu}$$

where, $L = 4\frac{A}{P}$ is length scale, A is cross-sectional area of the channel, P is wetted perimeter of the channel, μ is the viscosity, p is the fluid density, V_{avg} is the average velocity of flow[6][7].

Re depends on material properties (density, viscosity), boundary conditions, critical velocity Reynolds number less than 25 are common in microfluidics owing to their small volumes and representing the laminar flow in which the viscous forces are dominant and it is used to express the smooth fluid motion where as high Reynolds numbers in contrary represents the high inertial forces as dominant expressing the flow variations and the turbulence [8].

B. Materials used for Microfluidic Device Fabrication

The materials of importance in microfluidic device fabrication are classified as:

1) *Substrates:* The substrates are broadly classified as:

- *Silicon and Glass Substrates*: These substrates are used when small channels are required to be fabricated in microfluidic system with high resolution and repeatability and can be integrated into clean room environments with ease.
- *Metals:* It is commonly used in MEMS fabrication and the commonly used metals are aluminum, titanium copper etc. Their fabrication requires micromachining etc. and multitude materials are used for MEMS fabrication characterized by mechanical , electrical , magnetic as well as chemical properties which includes young's modulus , density, Poisson's ratio fracture toughness etc. eg: PCB[16].
- *SOL Gels:* These are silicate based compounds formed by condensation of $Si(OH)_4$ by loss of water. It requires formation of Si-0 network by thin film and should not contain OH and SOG is prone to shrinkage.

The PCB is used as substrate here.

2) *PDMS:* PDMS is nearly ubiquitous i.e. commonly used material owing to its ease to use aided with a protocol, economic considerations and its transparency. The empirical formula of PDMS is $(C_2H_6OSi)_n$. If *n* is number of monomer repetitions, then PDMS may be liquid for poor *n* and semi solid if the value of *n* is large. PDMS i.e. Poly Di-Methyl Siloxane is commonly used in microfluidic applications under the product name as Sylgard184.

PDMS becomes stable and inert when comes in contact with chemicals and is also glass fusible since PDMS is inert, nonflammable and transparent optically due to its low cost and ease of use [9]. PDMS often becomes an elastic solid forming a hydrophobic surface after it is activated or cross linked. This feature is the main reason that PDMS surface never get wetted by polar molecules such as water which otherwise can lead to hydrophobic contaminant absorption. When PDMS comes in contact with the flat substrate, there exists weak temporary bonding which is spontaneous [10]. Except for low soluble liquids as isoproponal, acetone and pyridine, organic solvents may cause swelling and hence can't make contact with PDMS.

This concludes that PDMS can be used with reusable SU-8 master mold there by forming a stable and reliable microfluidic soft lithography device [9, 11]. The elastomeric properties of PDMS also make it vulnerable to specific problems such as the problems due to pressure gradients or gravitational deformations that causes closing of channels [12]. Commonly used PDMS are PDMS RTV – 615 and Sylgard PDMS 184.

Sylgard 184 PDMS is inert, sterilizable and used for rapid fabrication and so commonly used material. Dow and corning's Sylgard 184 is the commonly used PDMS in the microfluidics. It is a two part system with mix ratio of cross linker agent Siloxane in 1:10 ratio. Any increase in this micro mix crosslinker ratio increases the rigidity of the PDMS [13] where as its mechanical properties can be changed by changing cure cycle [14] out of the mould leaving behind the replica of microchannels in PDMS which accomplishes the fabrication of microfluidic device[14][15].

3) *Copper Sulphate ($CuSO_4$) Solution:* It is used for electrolysis purpose in which the thickness of copper on PCB is increased by deposition of more Cu on substrate obtained during electrolysis of $CuSO_4$ solution which acts as anode and releases Copper on ionization into the solution which are deposited on cathode during electrolysis. PCB acts as cathode.

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4) *Electron Microscope:* A precise high resolution electronic microscope is used to study the patterned PDMS layer. The Flow chart for PDMS microchannel fabrication is shown in Figure 1.

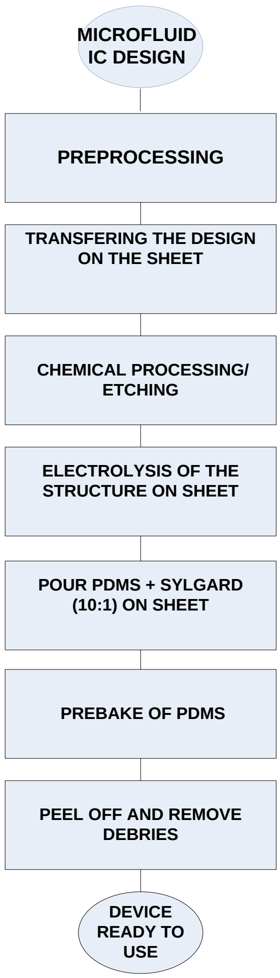

Fig. 1. Flow chart for steps of PDMS channel fabrication

II. METHODOLOGY

The methodology used for fabrication of different channel shapes to study effect of shapes on fluid flow is divided into three stages- Stage 1 includes the designing and transfer of different patterns of channel shapes on PCB , Electrolysis of patterned PCB occurs in stage 2 followed by the mold creation and PDMS removal in stage 3.

A. *Stage 1*

It includes the channel pattern designing and pattern transfer to PCB.

1) *Pattern designing:*

The designing of each shape of microchannel of varying dimensions is made using Autocad software. The different shapes designed are shown in Fig. 1 with varying widths of the channels as listed in Table I.

TABLE I

DIMENSIONS OF I- SHAPED CHANNEL

Shape /part of the Device	Dimensions I	Dimensions II	Dimensions III
Collecting part	10mm	10mm	10mm
Length	2mm	1.6mm	1.2mm
Width	2mm	1.6mm	1.2mm
Channel width	.5mm	.4mm	.3mm

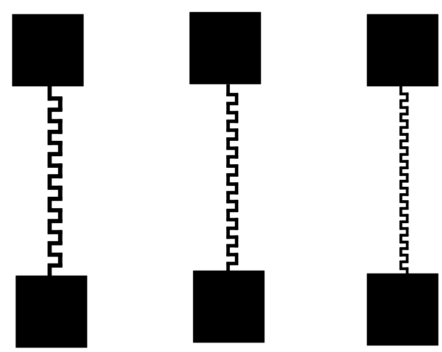

Fig. 2. I-Channel shape with square inlet and outlet

The Table II shows dimension of inverted Y–shaped microchannel and represented in Figure 2.

TABLE II

INVERTED Y- SHAPED MICROCHANNEL

Shape /part of the Device	Dimensions I	Dimensions II	Dimensions III
Collecting part	10mm	10mm	10mm
Channel width	1.5mm	0.6mm	.4mm

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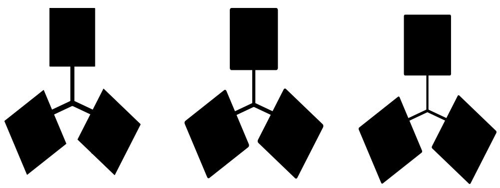
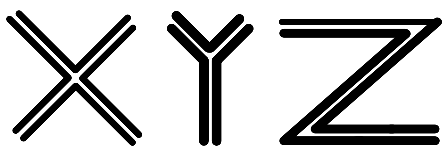


Fig. 3. Inverted Y- shaped with square representing inlet/outlet.

Some other shapes microchannel designed are shown in Fig. 3, with two inlets and two outlets (Fig. 3a), two inlet and one outlet (Fig. 3b), and single inlet and outlet (Fig. 3c).



(a) (b (c)

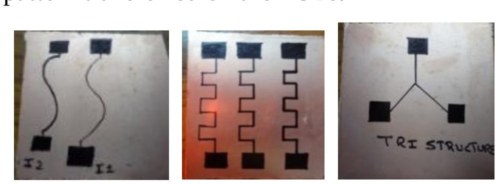
Fig. 4 Different structure of microchannel.

2) Pattern Transfer:

Before transferring pattern, it is essential to ensure that PCB is dirt free so acetone is used for swab coating the PCB and then distilled water is used to clean PCB for zero impurities.

The pattern designed is printed on a commercial photo paper and then transferred on dirt free PCB using a heat press. The pattern on heat paper is aligned on PCB and then pressed with a heat press that applies pressure of hundreds of pound and has precise temperature control which can't be obtained by conventional home hand irons. The pressure is applied until the heat paper melts away leaving behind the pattern on PCB. The temperature required for heat transferred pattern is between 375^0F to 425^0F and pressure lies between 40-80 psi.

The patterned PCB is etched using ferrous sulphate etchant solution and post baked for quick dry. Figure 4 shows the various pattern transferred on the PCBs.



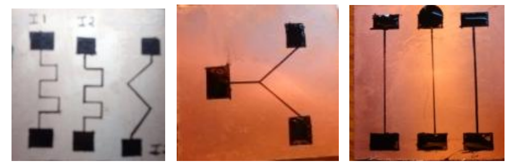


Fig.5 Patterned transferred on the PCB.

B. Stage 2 : Electrolysis

The etched patterned PCB is subjected to electrolysis when dipped in an aqueous copper sulphate solution which is required to increase the depth of copper channel due to excess deposition of copper on cathode (PCB) from during electrolysis of copper sulphate solution (anode). The whole setup is shown in Fig. 5. The ionization of copper sulphate solution and deposition of Cu on cathode is given in Equation 1, 2, and 3 respectively.

$$CuSO_4 \Longrightarrow Cu\,(++) + SO_4(-.-)$$

$$Cu(++) + 2e\,(-) \Longrightarrow Cu$$
$$Cu \Longrightarrow Cu\,(++) + 2e(-)$$

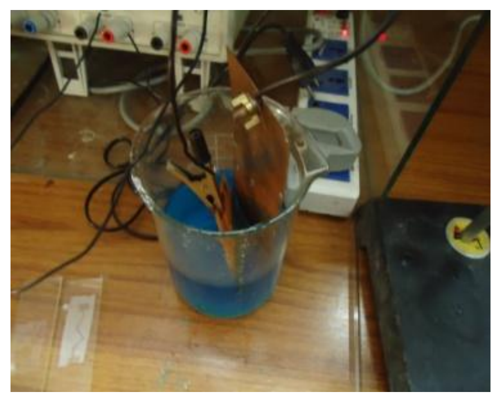


Fig. 5 Electrolysis setup used in experiment.

The electrolysis of the etched patterns is done in order to obtain the desired ridges of the PDMS which in turn results in the desired channel sizes/ depths of microchannels.

C. Stage 3: Mold Creation and PDMS Removal

The molds are created using Dow corning Sylgard 184 PDMS. It is basically a silicone elastomer kit containing two chemicals: Base agent (part A) and curing agent (part B). Both chemicals are transparent and viscous in nature. Base agent is mixed with curing agent in the mass ratio of 10:1 for creating molds when poured on patterned PCB (Figure 5). The mixture is poured evenly and then post baked at 100^0C for 35 minutes[16][17][18]. Before pouring the PDMS, we

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will clean the PCB with the acetone and distilled water so that no impurities left on the PCB. The hardened PDMS is peeled off with utmost care. The inlet and outlet ports are drilled on the PDMS replica and the debris are removed. This pattern is ready is used and studied under electron microscope for further investigations.

III. RESULTS AND DISCUSSIONS

Investigations were carried out to fabricate different structures of the microchannel on the PCB. Final snapshot of the microchannel are shown in Fig. 6. The replicas of the trenches formed on the PCB are transferred on the PDMS shown in Fig. 7. Optical microscopy of the PDMS replica is carried out to verify the continuous micro-path for fluid movement shown in Fig. 8.

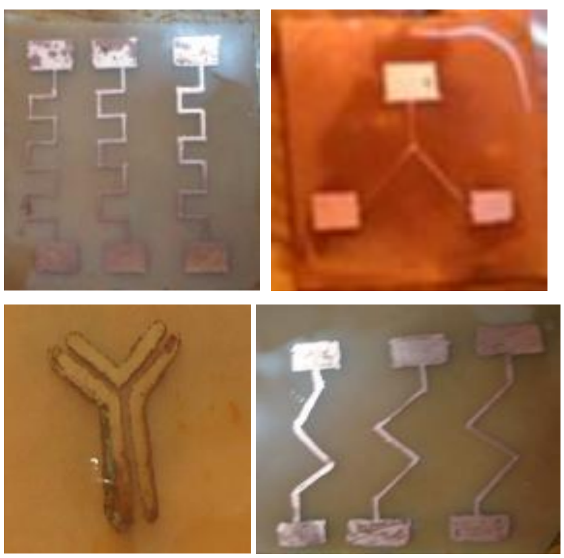
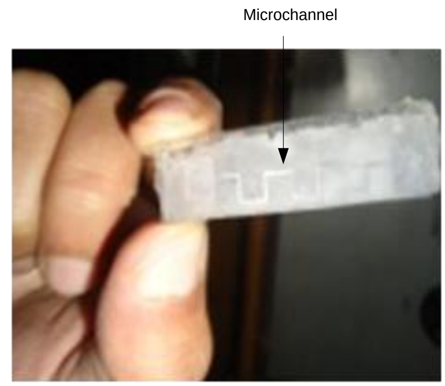


Fig. 6 Final structure on the PCB.

(a)

(b)



(c)

Fig. 7: PDMS replica of fabricated microchannel.

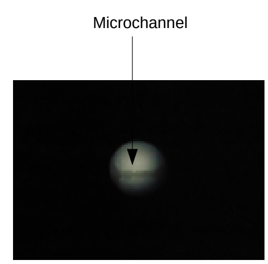


Fig. 8 Optical microscopy of the microchannel.

IV. CONCLUSION

Investigations are carried out to develop a cost effective technique for the fabrication of microstructure. Layouts of the micro designs were made using commercial available software's. These designs were successfully transferred on PCB using heat-press method. Etching is an important factor

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determining the structure imprint on the metallic layer. Thus different time varying etching processes were performed until final break free structure is obtained. Replicas of the structures were fabricated using PDMS which gave the trenches on it. Trench depth was increased by depositing copper material on the metallic part of the structure using electrolysis process.

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