Enabling novel Lab-on-chip applications through optimization of integrated micropillar pumps

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Abstract

Prediction and reduction of pressure drop and resistance flow in micropillar arrays is important for the design of microfluidic circuits used in different lab-on-a-chip and biomedical applications. In this work, a *diamond microchannel integrated micropillar pump* (dMIMP) with a resistance flow 35.5% lower than circular based micropillar pump (cMIMP) has been developed via the optimization of the fluid-dynamic behavior of different post shapes in a low aspect ratio (H/D ranged from 0.06 to 0.2) integrated pillar micro-channel. Flow through the fabricated samples has been numerically solved and experimentally measured, with an agreement higher than 90%. The analysis of the results indicates that although porosity can be a determinant parameter to predict the resistance flow of MIMP, other geometrical parameters like, side distance between posts or post shape, play a major role in this scenario.

Keywords: Microchannel integrated micropillars (MIMP), Resistance flow and pressure drop

1. INTRODUCTION

Microchannels with integrated micropillars (which we called MIMP in this paper) present increased heat and mass transfer coefficients by a great surface-area-to-volume ratio which make them a novel design in a vast verity of applications [1] [2] [3]. Furthermore, in the recent years, this microstructure design has shown high potential in biological and life sciences to analyze cells, DNA, proteins and chemical reagents [4] [5]. Understanding the effect of geometrical parameters of microchannels with integrated micropillars (MIMP) is important to improve and optimize the design of all the aforementioned microfluidic devices. There are few experimental and numerical investigations that characterize the pressure drop and flow resistance in MIMP, key parameters to obtain the flow resistance of MIMP structures. [6] [7]. The aforementioned studies provide valuable insight into the pressure drop and flow resistance in cylindered MIMP

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but there are a lack of the study on the hydrodynamic effect of different shape MIMP with low aspect ratio (H/D ranged from 0.06 to 0.2), which in microfluidics are very valuable as micro capillary pumps. On the other hand, most of the mentioned studies used silicon as a manufacturing material whereas most microfluidic applications use PDMS. Despite its many outstanding characteristics, PDMS is a low Young modulus material that under pressure can suffer considerable deformations [8]. In this study, the use of a novel fabrication technique that uses a thiolene resin to harden PDMS minimizes this effect.

2. FABRICATION PROCEDURE

The fabrication technology for the MIMP channels is a modified soft-lithography process, which withstands high pressures with low PDMS deformations. Fig. 1 summarizes the different steps of this technology and a sample of the fabricated MIMP structures using this fabrication methodology.

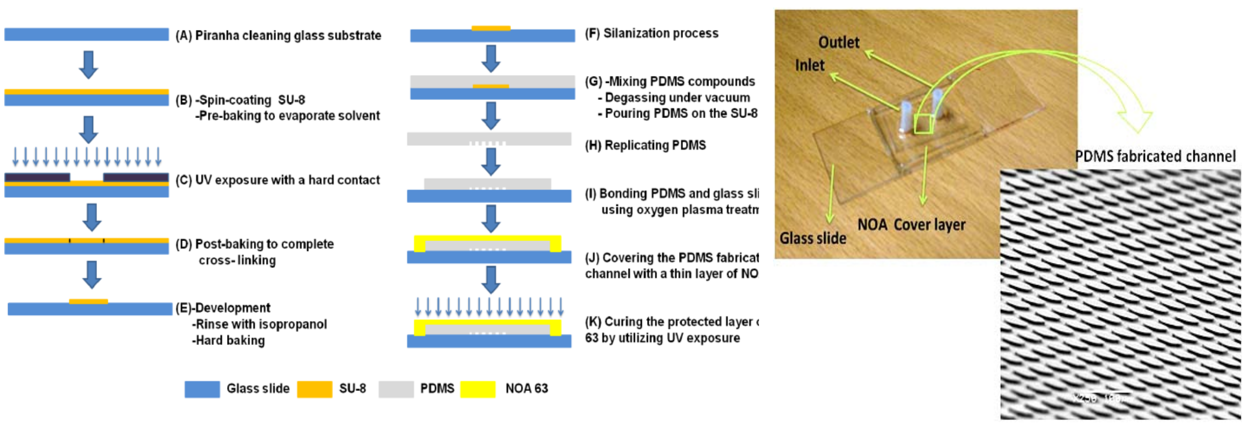


Figure 1. Microfabrication process steps (a)-(f) SU8 mold (g)-(k) Hardened PDMS microchannel integrated micropillar (MIMP) fabrication and Optical image of a packaged MIMP and SEM detail of the integrated micropillars

3. NUMERICAL MODELLING OF MIMP UNIT CELL

In order to maximize the pumping efficiency in microdevice applications, the resistance flow should be minimized through the design. Numerical analysis is an indispensable tool due to the lack of analytical solutions for the resistance flow calculation through MIMPs. On this basis, the flow through MIMPs is solved numerically for different pillar shapes and different pillar arrangements. Ansys Fluent 12.0.1 software, which is based on finite volume method, was used to perform the numerical simulations. MIMP can be simulated by considering flow around half of isolated pillar as unit cell (See Fig.2). The flow is fully developed with constant properties, which enabled us to model the half of unit cell for calculating the pressure gradient in the whole MIMP by imposing periodic boundary condition.

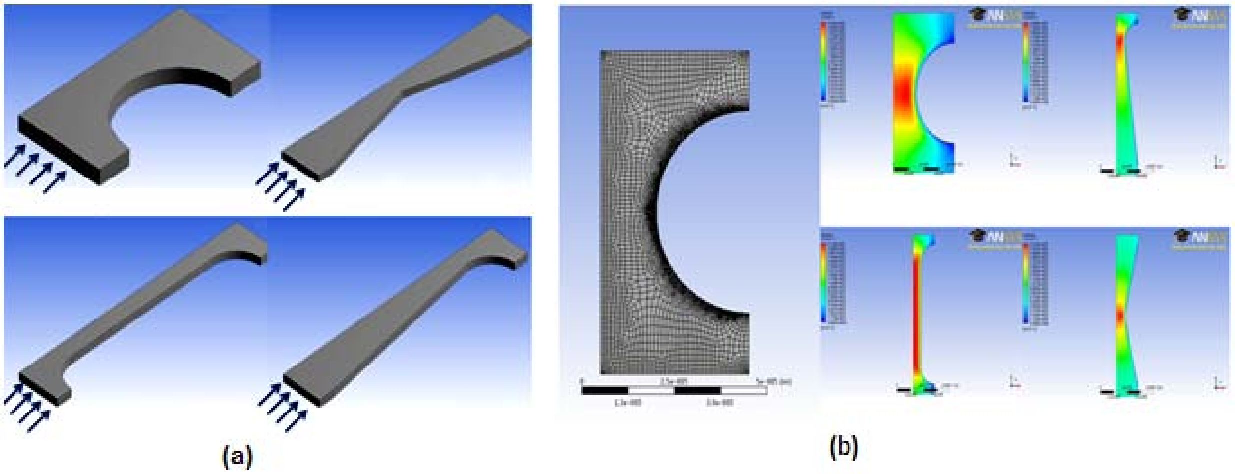
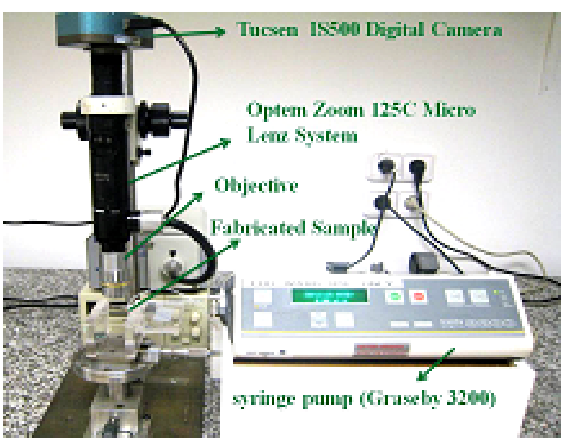


Figure 2. a) Numerical modeled half of unit cells for circle, diamond, elongated and pine post shapes b) The produced numerical grid of considered unit cell and the velocity contour of different post shape

4. MODEL VALIDATION

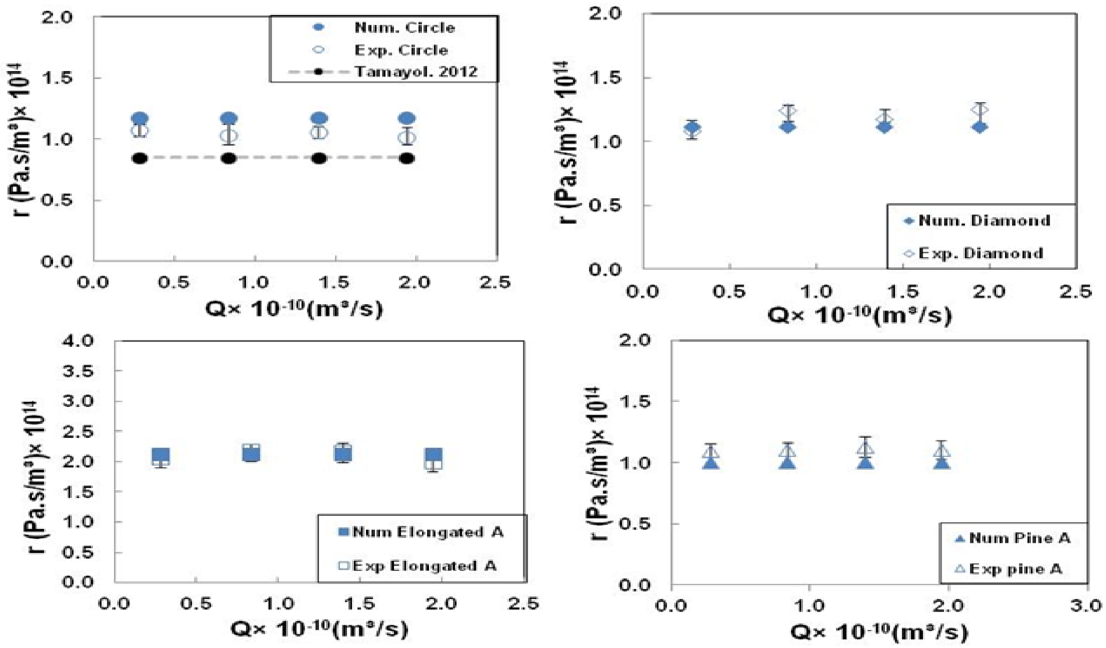
The proposed microfabrication process that uses a thiolene resin to harden the PDMS MIMP channels opens the possibility to implement MIMP pumps and whole microfludic system in PDMS with a behavior similar to glass fabricated devices. Therefore, testing of the packaged



Sample	D	SD	FD	LD	Porosity
Circle A	52	28	32	52	0.68
Circle B	98	27	31	98	0.53
Diamond A	54	20	42	193	0.70
Diamond B	95	19	40	194	0.65
Elongated A	53	20	21	202	0.38
Elongated B	104	19	20	201	0.32
Pine A	54	23	62	206	0.71
Pine B	103	25	60	205	0.64

Figure 3. The experimental setup for pressure drop measurement and the average dimensions (μm) of the MIMP fabricated samples. D and LD are the Short and large post diameter, SD Side distance and FD Forward distance between posts

MIMP pumps are conducted using distilled water. The testing setup and the geometrical parameters of manufactured devices has been measured using SEM image analysis are shown in Fig.3. The resistance flow versus the volumetric flow rate for circle, diamond, elongated and pine posts using the numerical and experimental values and the results presented by Tamayol [7] are shown in Fig.4.



5. Conclusion

The pressure drop and flow resistance of laminar flow through low aspect ratio MIMP with different shapes and geometrical parameters were experimentally and numerically determined. The obtained results show the maximum flow resistance of elongated post shape MIMPs in comparison to the other MIMPs, while diamond post shapes presents the minimum resistance flow. In terms of geometrical parameters, post diameter in the flow direction and side distance between two adjacent posts are the most effective design parameters to control the pressure drop of MIMPs.

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