Sensors and Actuators A 234 (2015) 195–205

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Structural parameter analysis and experimental study of micropumps with saw-tooth microchannel

Guan Yan-fang*, Liu Chun-bo

College of Mechanical Engineering, Henan University of Technology, Zhengzhou 450001, China

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 13 March 2015
Accepted 3 September 2015
Available online 7 September 2015

Keywords:
Micropump
Vortex
Structural parameter
Flow rate

ABSTRACT

The changing trends of vortex, pressure loss, microchannel efficiency and instantaneous flow rate along with Reynolds number are discussed based on the structural parameters of a saw-tooth microchannel that include diffuser angle, sectional width, length, taper angle and depth. Through finite element analysis it is shown that the nozzle flow is steadier than diffuser angle. The optimal range of diffuser angle is 5–9°. The channel efficiency decreases with an increase of sectional width, and the optimal value is 0.04 mm according to the technology conditions. The pressure loss increases with increasing length. The channel performance is best when the taper angle is in the range 20–40°. The channel efficiency increases with an increase of depth, but, with this increasing depth, the wall friction force increases, and the fabrication processing becomes more difficult. Finally, five micropump structures were designed and fabricated with deep reactive ion etching technology based on silicon wafers. The five micropumps were irreversibly sealed with polydimethylsiloxane (PDMS) on both sides using ultraviolet irradiation of the PDMS. For testing the flow rate and pressure of the five micropumps, a test-bed was established. The results show that the flow rate and pressure of one of the micropumps are maximal values under sine, square and triangular driving waves. This agrees well with the results of the structural parameter analysis. When the driving frequency is 200 Hz, the maximum flow and pressure are 63.6 μl/min and 1.3 kPa respectively.

1. Introduction

With the development of lab-on-a-chip technology, microfluidics driving technology has become very important for researchers. Acting as the source of power of fluid transmission, micropump performance is very much related to the complete working status of microfluidic systems. So micropumps have become a hot research topic and an important part of microfluidic systems [1–3]. Previous research concentrated on the structure, material and fabrication technology, such as that of Olsson and Stemme who carried out a detailed analysis of the processing technology and encapsulation mode of diffuser/nozzle micropumps [4,5]. Nguyen fabricated erect valveless micropumps based on printed circuit boards [6]. With microsystem manufacturing becoming a mature field, the focus turns to the inner flow performance analysis of micropumps. For example, Wang analyzed the relationship of pressure loss and Reynolds number with diffuser angle [7]. Liu analyzed the influence of size and roughness of microchannels on friction factors under different pressures [8]. But the influence of microchannel structural parameters, such as diffuser angle, depth, length, sectional width and so on, has not been reported for novel saw-tooth micropumps.

2. Structural parameter analysis of novel saw-tooth microchannel

2.1. Structural design

According to the literature [9,10], the microchannel length of a plane type valveless micropump is 10–80% shorter than that of a vertical type. So, the plane type micropump has been adopted in this paper. The main structural parameters of the microchannel include diffuser angle, sectional width, length, depth and taper angle in Fig. 1(a). During analysis the template that was selected was that the length, sectional,width, depth and diffuser angle are respectively 1.093 mm, 0.04 mm, 0.01 mm, and 7° and 10° [4]. The ranges of all structural parameters are shown in Table 1. The comparison between the length and tooth number are shown in Table 2. The integral size and three-dimensional exploded view of the micropump and saw-tooth microchannel is shown in Fig. 1(b) and (c) (the unit is cm in Fig. 1(b)). The whole micropump is made up of five parts: upper cover plate, glass wafer, pump body (sili-

* Corresponding author.
E-mail addresses: sgyffg@126.com, gyf605@126.com (G. Yan-fang).

http://dx.doi.org/10.1016/j.sna.2015.09.003
0924-4247/

Table 1
Structural parameters of saw-tooth microchannel.

Depth (mm)	Sectional width (mm)	Diffuser angle (°)	Taper angle (°)	Length (mm)
0.01–0.2	0.01–0.16	3–30	10–80	0.8318–2.7328

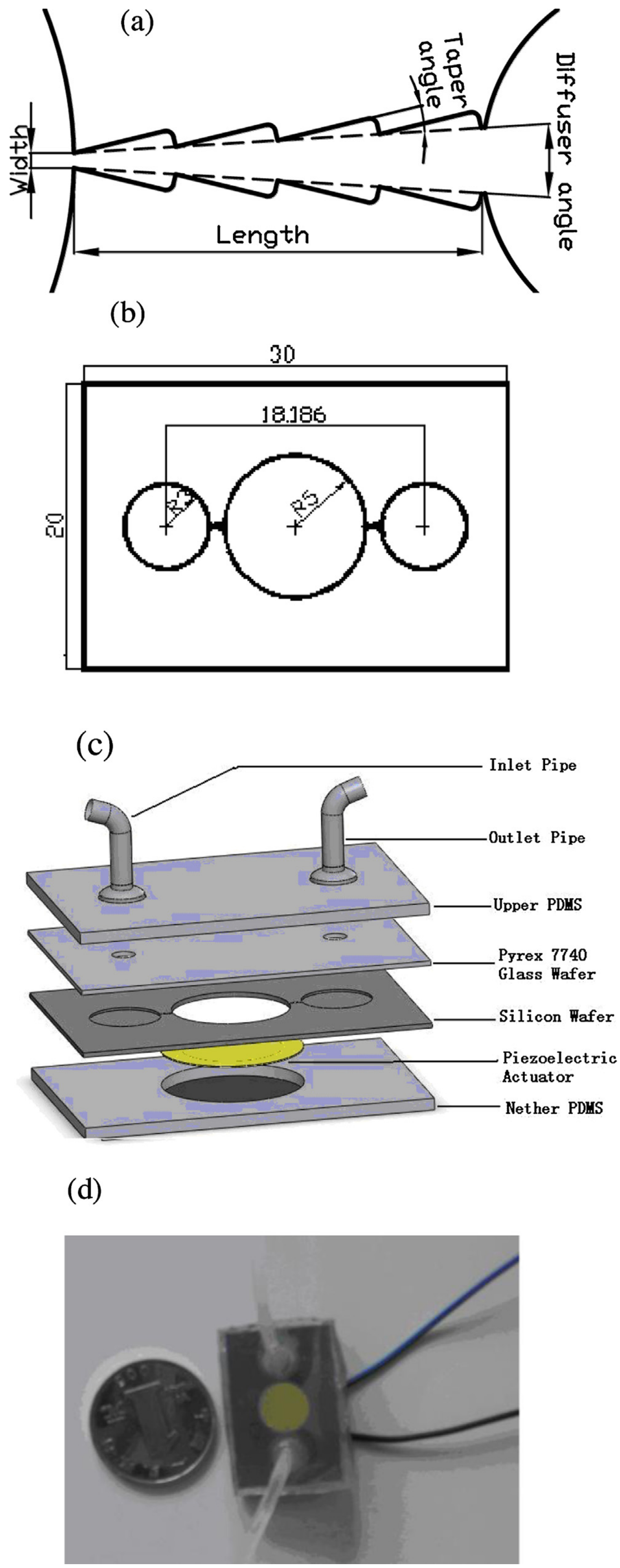

Fig. 1. Three-dimensional structures of the micropump.

Table 2
comparison of tooth number and length.

Tooth number	Length (mm)
3	0.8318
4	1.0930
5	1.3663
6	1.6396
7	1.9129
8	2.1862
9	2.4595
10	2.7328

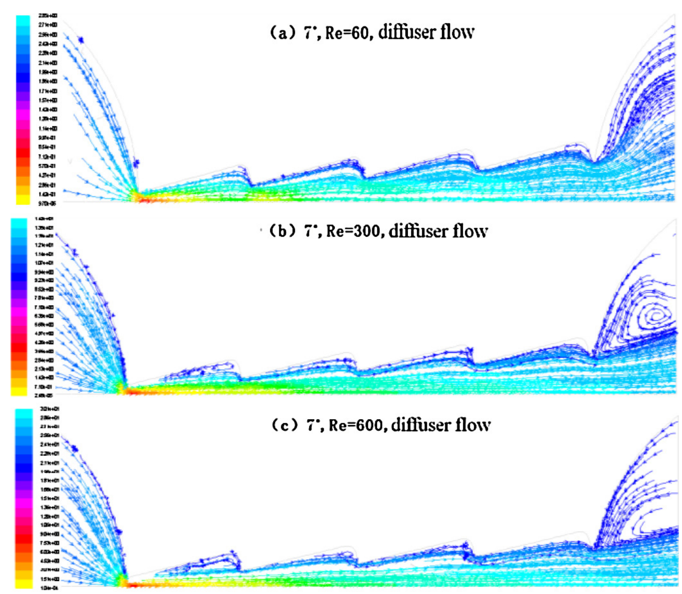

Fig. 2. The diffuser flow for 7° diffuser angle vs. Reynolds number.

con wafer), piezoelectric actuator and lower cover plate. The pump body that is the important part contains the microchannel and chamber. The overall dimensions and formal shape of the micropump are shown in Fig. 1(d).

2.2. Structural parameter analysis

Finite element analysis has been adopted as the method of parameter analysis with the diffuser and nozzle directions. The influence of the structural parameters on performance parameters that include vortex, flow rate, pressure loss and channel efficiency has been discussed [11].

2.2.1. Diffuser angle

Diffuser angle is the important parameter of the saw-tooth microchannel. The range of diffuser angle is 3–30°. The diffuser flows for 7° are shown in Fig. 2 with Reynolds number (*Re*) equal to 60,300 and 600 (the unit of velocity is m/s in Fig. 2 and other figures). The diffuser flow is steady and there is no vortex when $Re = 60$ (Fig. 2(a)). A vortex appears at the first and second tooth when *Re* increases to 300 (Fig. 2(b)). When $Re = 600$ a vortex appears at the third and fourth tooth (Fig. 2(c)). Furthermore the exit vortex increases with increasing Reynolds number [12].