Journal of Science and Technology ***54*** *(1A) (2016) 168-174*

FABRICATING THE MICROFLUIDIC CHIP WITH LENGTH-AND-DIAMETER RATIO OF CHANNEL AROUND 3000

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Received: 03 September 2015; Accepted for publication: 26 October 2015

ABSTRACT

Microfluidics is a device that accurately controls the motion of fluid flow with a very small amount of liquid. This field has been studied with many empirical applications in physics, chemistry, biochemistry, nanotechnology and biotechnology. Depending on particular application, the length-and-diameter ratio of channel is designed specifically in order to gain the highest efficiency for physical response and chemical reaction, etc. In this report, microfluidic chips, based on PDMS material, fabricated by soft lithography with the length-and-diameter ratio of channel 3000 times, have been fabricated for the research on biomedical orientation.

Illustration of microfluidic chip with straight and spiral shape and the length-and-diameter ratio of channel around 3000.

Keywords: microfluidic chip, PDMS, soft-lithography.

1. INTRODUCTION

In the past two decades, the microfluidic chips, which are able to miniaturize the facilities in experiments with the micro volumes of fluids (µL, nL, pL or fL), demonstrated useful abilities and practical applications in the multidisciplinary field, such as health diagnosis, genome and protein research, chemical analysis, environmental assessment and detection of pathogens, as well as in the field of other scientific studies [1 - 4]. The equipment using Micro Total Analysis Systems (µTAS) is more advantageous than traditional sophisticated, expensive and closed systems, especially in the ability to control fluid flow precisely, minimize the volume of testing solutions, with short reaction time, allowing analyzing multiple channels in parallel, with less operating energy, and low production costs [5].

The research on microfluidic chips, associating with μTAS, has attracted much attention of many researchers in the world as well as in Vietnam. According to specific applications, configuration of microfluidic chip will be designed suitably about the length, width and height. Specifically, in the systems detecting the dye concentration based on fluorescence intensity obtained by J. Hubner et al. [6], the microfluidic chip was devised with 500 μm width flow channel. In the design of a fuel cell of E. Kjeang et al. [7], microfluidic chip had a height of 120 μm and a width of 2000 μm. In the publication of Tran Hong Nhan et al. [8], the μTAS were designed to determine the concentrations of AlQ_3, with 200 μm width and 20 μm height flow channels. In this study, we have developped and improved microfluidic chips with miniaturization the channel size down to 100 μm width, and extending the path channel with 02 different configurations (straight and spiral shape) for diversified structures for biomedical applications in next steps.

The soft lithography method has proved to be a simple, cheap and rapid prototyping method to fabricate PDMS-based microfluidic channels [9 - 12]. These are important factors of the chip fabrication for practical applications.

PDMS is the abbreviation of polydimethylsiloxane ($H_3[Si(CH_3)_2O]$ $NSi(CH_3)_3$), with typical characteristics:

- Transparent, colorless, chemically inert, non-toxic and non-flammable.
- Insoluble in water and ethanol, but soluble in Benzene (C_6H_6), Chloroform ($CHCl_3$), Toluene (C_7H_8) and some other organic solvents.
- High transmittance (around 99 %) from the 240 nm to 1100 nm wavelength, being compatible with a variety of technical analyses and optical microscopy applications.

After mixing with hardener (called PDMS resin), PDMS will become a non-sticky material. The surface properties of PDMS will change due to oxygen plasma treatment process, introducing the polar functional group (SiOH) on the surface of the PDMS. This adheres PDMS to the surface of glass easily.

2. EXPERIMENTAL

PDMS microfluidic chip was manufactured via several steps. First, a mould of straight or spiral channel structures was prepared. Second, PDMS resin was poured onto the mould and heated for one and a half hours for solidification. Then it was removed from the mould, and then holes were punched to make fluid inputs or output ports on this PDMS layer. The next step was to treat PDMS layer and glass substrate under oxygen plasma to introduce the polarization adhesion to be much easier in sticking process.

The mould of straight or spiral channel structures for microfluidic fabrication were made of bakelite plastic covered with a 20 µm thickness of copper and zinc layers used in the electronic industry for reducing the manufacturing costs of mould [13, 14]. Due to the fact that the thickness of the copper and zinc layer was only 20 µm thick, fabricated channels were still suitable with small volumetric fluid flow in µL. The mould were designed with a channel width of 200 µm and 20 µm in height.

PDMS (Sylgard 184) was mixed with hardener in 10:1 ratio by weight and the mixture was stirred properly for 5 minutes, then centrifuged to remove air bubbles. Then, the PDMS resin was poured into the mould and annealed at 65 ºC for 2 hours to accelerate the solidifying process of PDMS mixture (Figure 1).

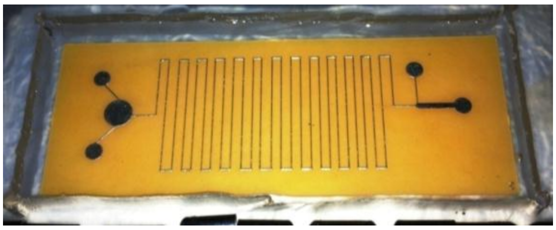

Figure 1. PDMS resin in mould after solidifying.

Figure 2. The PDMS surface with straight pattern of channel after being peeled off from the mould.

The PDMS layer, with the formation of channels and reservoirs as designed, was peeled off from the mould (Figure 2) and two holes were punched for inlet ports and another one for oulet port. These two inlets were connected to indicating and analytic solutions. The outlet was used for getting solution from reservoir. Then, this PDMS layer was sticked onto the glass substrate for microfluidic chip fabrication.

The sticking technique of PDMS layer and glass substrate without deformation or damage the channel is the most important step of PDMS-based microfluidic chips. In addition, the elasticity of different materials in solification process also causes the various types of deformation for chip fabrication. In order to overcome this problem, oxygen plasma technique has been used. This technique has created the polarization between two surfaces, completely dismissed intermediate gas layer between them during sticking process. The Van-der-Waals force between two surfaces (the size of channel is very small compared to pasted surface) is large enough for adhesive and can suffer the high pressure during the injection of fluid into the microfluidic chip. At that time the contacting area of PDMS layer and glass surfaces obtained the dark colour due to the good wettability between PDMS and glass surfaces. Figure 3 (a, b) show the straight and spiral channels of microfluidic chips after completing the steps above.

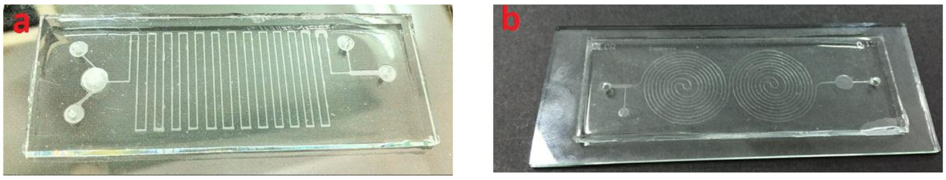

Figure 3. The microfluidic chip with straight (a) and (b) spiral channel after finishing.

In order to check the quality of microfluidic chip after fabrication and control the fluid flow in chip, micro-flow pump system (using step motor) is designed to connect the chip, able to pump the micro fluid around µL/s (Figure 4). This allows the control fluid flows in micro channel system correctly.

The micro-flow pump system includes many components: the microfluidic pump, the control panel, the one-way valve and the Teflon pipes.

The steps for surveying the fluid flow in microfluidic chip with micro-flow pump system:

- Starting the pump, calibrating and connecting the micro-flow pump system to microfluidic chip.
- Connecting the micro-flow pump to analytic solution.
- Adjusting the speed of the pump (rpm) and starting the pump.
- After pumping, microfluidic chip can be reused by heating chip to evaporate the remaining fluid.

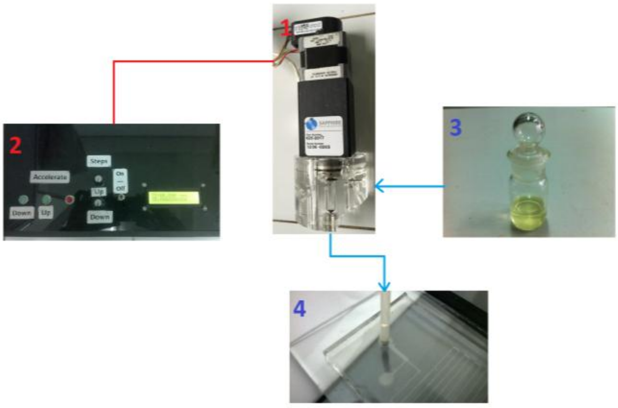

Figure 4. The micro-flow pump connecting the microfluidic chip. 1) The micro-flow pump system with step motor. 2) The control panel. 3) The analyzed solution. 4) The microfluidic chip.

3. RESULTS AND DISCUSSIONS

We have successfully fabricated two types of microfluidic chips with straight and spiral channel structures. The spiral channel structure has half capacity of the straight one. The parameters of length, width, height and volume of two types of chip channel flow are shown in Table 1.

The shape of the straight channel of microfluidic chip, with the length-to-width ratio of 2500, is easy to manufacture due to the large distance between two channels. However, the substances in the solution can be deposited at the folded points between the channels. In order to overcome this limitation, the channels without folded points are designed, named the spiral channel, with the length-to-width ratio of 3200.

The fabricating process of spiral channel microfluidic chip is more difficult than the other due to the fact that the width of the spiral chip is 125 microns, 37.5 % less than 200 µm width of the other one, leading to micro-flow channel cross section of the microfluidic chip about 0.0025 mm^2 to 0.004 mm^2, so the strong pressure is needed to supply to pump water into the micro flow channels. Such pressure can cause cracks, leakage between the channels, damaging microfluidic chip [15]. Therefore, the miniaturization channel is a significant step in the study of microfluidic chip fabrication.

Table 1. The fabricating parameters of two sets of microfluidic chips with straight and spiral channels.

	Straight channel	Spiral channel
Length (mm)	500	400
Width (mm)	0,2	0,125
Height (mm)	0,02	0,02
Volume (μL)	2	1

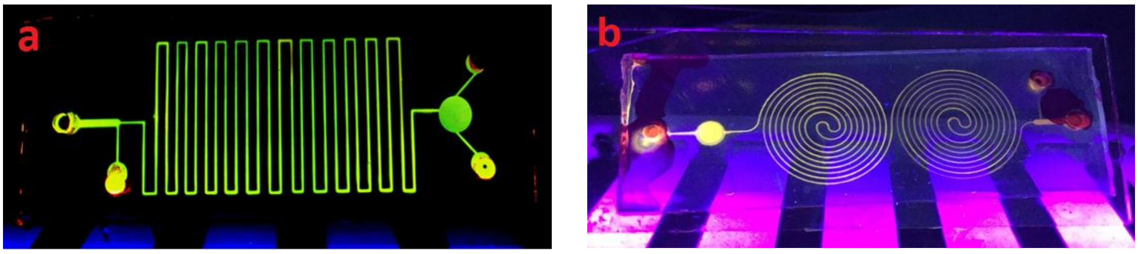

Figure 5. Microfluidic chips of two sets of channel: straight (a) and spiral are radiating under UV light.

In order to test the microfluidic chip, we pump Rhodamine 6G solution (R6G) into the channel, then exciting under ultra-violet radiation. R6G is strong fluorescence under UV wavelengths, so the current of this solution is clearly observed (Figure 5 (a,b)) and there is no leakage to see here. This demonstrates that the microfluidic chips have been fabricated successfully.

Next, we check the reliability of microfluidic chip via multiple surveys with micro flow pump motor step, Figure 4, by pumping distilled water into the channel with the different pump speeds (rpm). With each pump speed, the time of flowing water in the channel is measured at least 10 times for each survey in every 10 minutes.

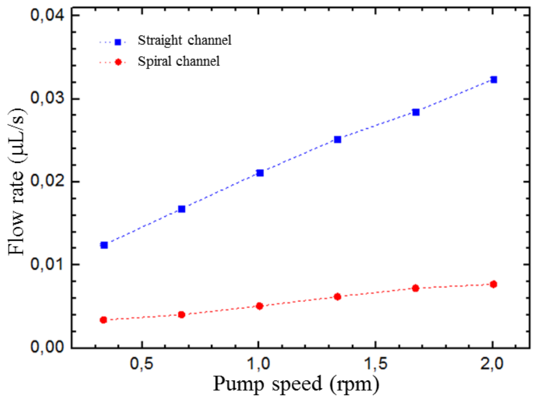

Figure 6. Evolution of flow velocity of two sets of channels: straight and spiral as a function of pump rate.

Figure 6 illustrated the linear relationship between the flow rate (μL/s) and pump speed, in which squares and dots correspond to straight and spiral channels, respectively. According to each pump speed, pressure generated in the system is different, causing the difference of current velocity in the channel. The cross section of spiral channel is smaller than the other, so flow speed in this spiral channel is smaller than the other, too.

Standard deviation of the flow rate in both two sets of channels is very small, around 10^{-4} μL/s, while standard deviation from spiral channel is 30 % smaller than the straight one. This demonstrates that the microfluidic chip has been successfully manufactured with small amounts of testing substrates, low uncertainty and completely reusable multiple times depending on practical purposes.

In summary, the length-to-width ratio of microfluidic chip, fabricated from PDMS materials by soft lithography process, can achieve 2500 times (straight channel) – 3200 times (spiral channel). This chip can control precisely the micro fluid motion, and is used for many practical applications in the fields of physics, chemistry, biochemistry, nanotechnology, biotechnology. The length-to-width ratio of the channel is designed in accordance to the particular applications so that these physical effects, chemical reactions, etc. occur with the highest efficiency, but with the lowest amounts of agents.

Acknowledgment. This research is funded by University of Science – Vietnam National University HoChiMinh City (VNU-HCM) under grant number T2015-09.

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TÓM TẮT

NGHIÊN CỨU VÀ CHẾ TẠO CHIP VI LƯU VỚI TỈ SỐ CHIỀU DÀI TRÊN ĐỘ RỘNG KÊNH KHOẢNG 3000

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Chip vi lưu (Microfluidics) là một linh kiện có khả năng điều khiển chính xác chuyển động dòng lưu chất với một lượng cực nhỏ. Lĩnh vực này đã và đang được nghiên cứu với nhiều ứng dụng thực tế trong các lĩnh vực vật lí, hóa học, hóa sinh, công nghệ nano, công nghệ sinh học. Tuỳ thuộc vào ứng dụng cụ thể mà tỉ số chiều dài/bề rộng kênh được quy định sao cho các hiệu ứng vật lí, các phản ứng hoá học,… xảy ra với hiệu suất cao nhất nhưng với lượng chất sử dụng thấp nhất. Trong báo cáo này, chip vi lưu từ vật liệu PDMS được chế tạo bằng phương pháp khắc mềm (Soft Lithography) với tỉ số chiều dài/ bề rộng có thể đạt được 3000 lần, đã và đang được chế tạo để phục vụ hiệu quả cho các nghiên cứu trong lĩnh vực y sinh.

Từ khóa: chip vi lưu, PDMS, khắc mềm.