FINGER-POWERED MICRODROPLET GENERATOR

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ABSTRACT

'Human-powered' microdroplet generators are ideal for droplet-based point-of-care diagnostics applications. Here we present a versatile 'finger-powered' microdroplet generator. The prototype system was fabricated via polymer-based micromachining processes. In this work, we have achieved: (1) the use of a human finger as the actuation force for droplet generation, (2) an integrated pumping system for actuating both droplet and solvent fluids simultaneously, and (3) the formation of microdroplets via a T-junction microchannel. During experimental device runs, both the formation of water droplets in oil and oil droplets in water were accomplished using a human finger, resulting in an average droplet size of 120 µm.

KEYWORDS

Micropump, Microdroplet, Microfluidics, Lab on a Chip, Point-of-care Diagnostics

INTRODUCTION

In situations that require urgent medical diagnostics, such as on the battle field or in technologically disadvantaged regions, the requirements of bulky and complex medical instruments often impede rapid treatment. Chip-based microfluidic technologies hold the potential to overcome these issues. Previously, chip-based microfluidics have been employed for basic scientific studies, such as cellular characterizations [1]. Recently, research has shifted to medical applications for quick point-of-care diagnostics [2]. In state-of-art microfluidic devices, microdroplet technology has been widely investigated [3, 4] due to several advantages: (1) quick mixing of samples via fast diffusion rates, (2) low background noise, (3) precise volume control of samples and reagents, and (4) well-established methods to handle droplets [3]. However, precise control of the flow inside a microchannel for droplet formation requires bulky and power-hungry syringe pumps, which remains a bottleneck in converting chip-scale microdroplet systems for broad markets (e.g., point-of-care applications.) Therefore, researchers in both academic and industrial labs have focused on the development of low-cost, low-power, and portable micropumps for the generation of microdroplets, as well as other hand-held diagnostic systems.

Previously, several groups have attempted simple methodologies to pump microfluidic systems via low power consumption mechanisms, such as the application of capillary forces on polydimethylsiloxane (PDMS) [5] and paper [6], as well as water-powered osmotic actuators and pumps [7, 8], negative pressure with pre-vacuumed

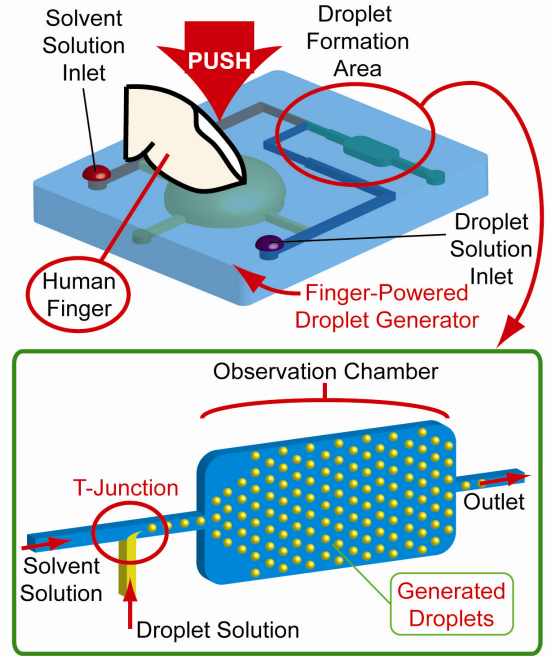

***Figure 1**: Concept of the finger-powered droplet generator. All the inlets are connected to the finger-powered pump. Pushed by a human finger, the droplet solution and solvent solution are infused into the device simultaneously. Droplets are formed with different flow rates at the T-junction.*

PDMS chambers [9], and finger-actuated pouches [10]. Unfortunately, the pumping head of capillary force is very limited, and the osmotic actuation responses are slow. The negative pressure chamber requires a vacuum pump and both negative pressure chamber and pouch-based approaches are single usage devices. Therefore, it is difficult to apply these previously demonstrated methodologies for specific requirements in microfluidics, such as the formation of microdroplets.

Previously, we have reported a finger-powered micropump system that can generate pressure to pump fluids into microfluidic devices [11]. In this paper, we propose and advance this technology by demonstrating a low-cost and easy-to-operate droplet generator that is capable of forming droplets using pressure from a human finger (i.e. without using any electricity). **Figure 1** illustrates the basic concept of the finger-powered microdroplet generator. We integrated the finger-powered microfluidic pump with several inlets and T-junctions. The device has a deformable chamber, which can be activated by a human finger to infuse droplet and solvent fluids simultaneously into the device for the formation of droplets. Infused solutions can form droplets at T-junctions by designing and controlling different fluidic resistances that result in different flow rates of droplet solutions and solvent solutions.

Continuous droplet formation can be accomplished by repeatedly pushing and releasing the membrane of the finger pump. As such, the low-cost, portable and easy-to-operate system could have promising applications for point-of-care diagnostics.

MATERIALS AND METHODS

Design

Figure 2 shows the design details of the system, consisting of four major components: (i) a pressure chamber (1cm in diameter) as the pressure generator to pump fluids, (ii) a safety valve to relieve excessive pressure, (iii) several one-way diode-type valves [12] to direct fluids from inlet to outlet ports, and (iv) a T-junction for the formation of droplets. The pressure chamber is connected to fluid inlets, and each inlet has a sample storage well. Both droplet and solvent fluids are infused from the storage wells into the microchannel sections when positive pressure is applied by the pushing operation of a human finger. When the pressure chamber returns to its original shape due to the elasticity of membrane material, negative pressure refills the sample storage wells from the inlet ports, while the diode valves prevent reverse flow. By repeating the push-and-release sequence, solutions can be continuously pumped.

The diode valve is made of two separated chambers with a thin membrane on top of them. When positive pressure is applied from one side, the membrane deforms upwards and two chambers are connected. When negative pressure is applied, the membrane is stuck to the wall separating the two chambers and backward flow is prevented. The T-junction has a 100μm-wide main channel for the solvent fluid and a 50μm-wide subchannel for the droplet fluid. Due to the difference of the fluidic resistance, the flow rate of the solvents is faster than that of the droplet solution. As a result, faster solvent movements cut into the flow of the slower droplet solution to create droplets. After the T-junction section, the flow slows at the observation chamber due to the wider channel (2500μm) for easy observation of droplets.

In order to prevent possible device failure due to overpressure in the pressure chamber, a safety valve has been integrated to the pressure chamber. The safety valve has the same structure as the diode valves, but with smaller chambers and a thicker separation wall, such that larger pressure is required to move up the thin membrane. This only happens if the pressure inside the deformable chamber is too high to allow excess pressure to be released to the air outlet port in the form of gas.

Additionally, the prototype system has two inlets for possible two different types of droplet solutions and these two inlets are connected together before the T-junction. The ability to infuse and mix different types of solutions before the formation of droplets enhances the functionality of the system. For example, applying whole blood from one inlet and glucose testing reagents form the other inlet could enable us to measure glucose level of the sample blood for diagnostics purposes.

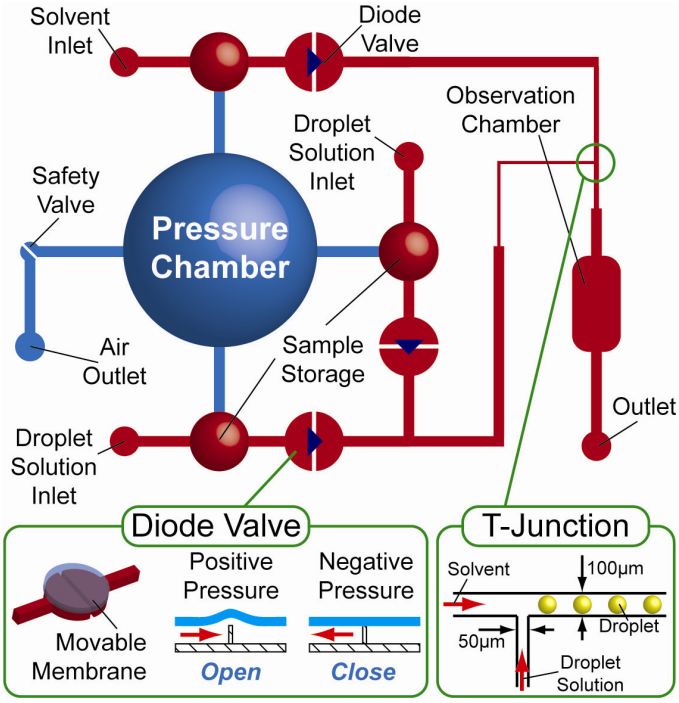

***Figure 2**: Design details of the device. Solvent and droplet solution inlets are connected to a single pressure chamber via sample storage wells. By repeating the push-and-release sequence using a human finger on the pressure chamber, sample solutions are guided from inlets to the T-junction section. Diode valves are used to prevent the backward flow when finger pressure is released. At the T-junction section, droplet solution is cut by the faster solvent flow to form microdroplets, which flow to the observation chamber.*

Fabrication

The system is constructed by a three-layer soft lithography microfabrication process using PDMS as the main material. **Figure 3** shows the fabrication process flow of the device. A common soft lithography process with layers of SU-8 is used to fabricate the master molds. After SU-8 is patterned, SU-8 droplets are deposited and cured to form the deformable chambers and sample storage chambers. These molds are transferred to PDMS, and the PDMS is cut into two layers after curing. Movable membranes are fabricated separately by spin-coating PDMS onto a silicon wafer on top of a uniform SU-8 coating to reduce the adhesion force between PDMS and silicon substrate. PDMS is coated at 2000rpm to achieve a 40μm-thick layer. This PDMS membrane and the two layers of PDMS components are bonded sequentially using oxygen plasma and assembled into a single device. To prevent misalignment of the PDMS layers, each PDMS layer is fabricated on a single silicon wafer to achieve the same shrinkage rate during the curing process.

Figure 4 shows the fabricated prototype device with dimensions of 3.4 cm in length, 2.75 cm in width, and 0.8 cm in thickness. The pressure chamber is located between the inlets with a good distance to prevent possible disturbance to the sample solutions during the push-and-release procedures. The observation chamber is located at a distance of 1cm from the pressure chamber.

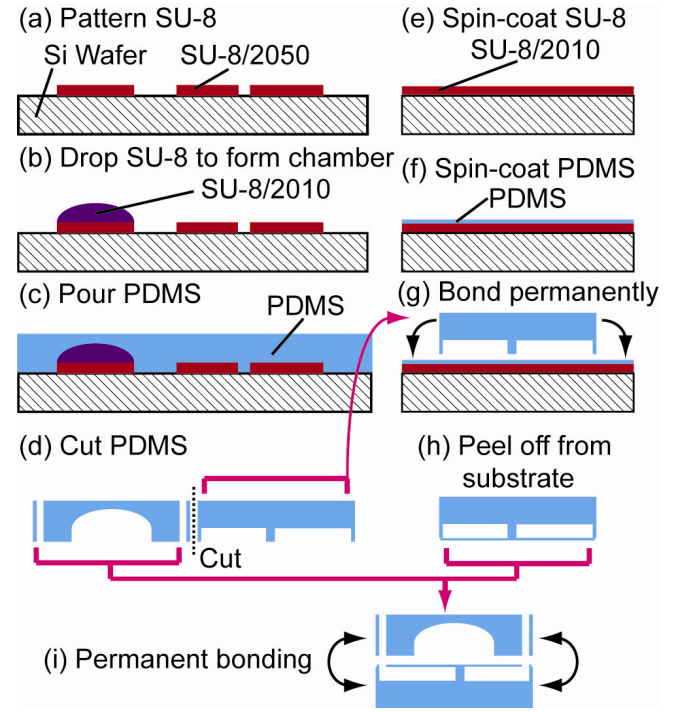

***Figure 3**: Fabrication Process. The device consists of three layers of PDMS, including a thin membrane for valves. Common soft lithography processes are utilized to fabricate each layer by using SU-8 as the primary molding material. The layers are permanently bonded with each other via Oxygen plasma treatment.*

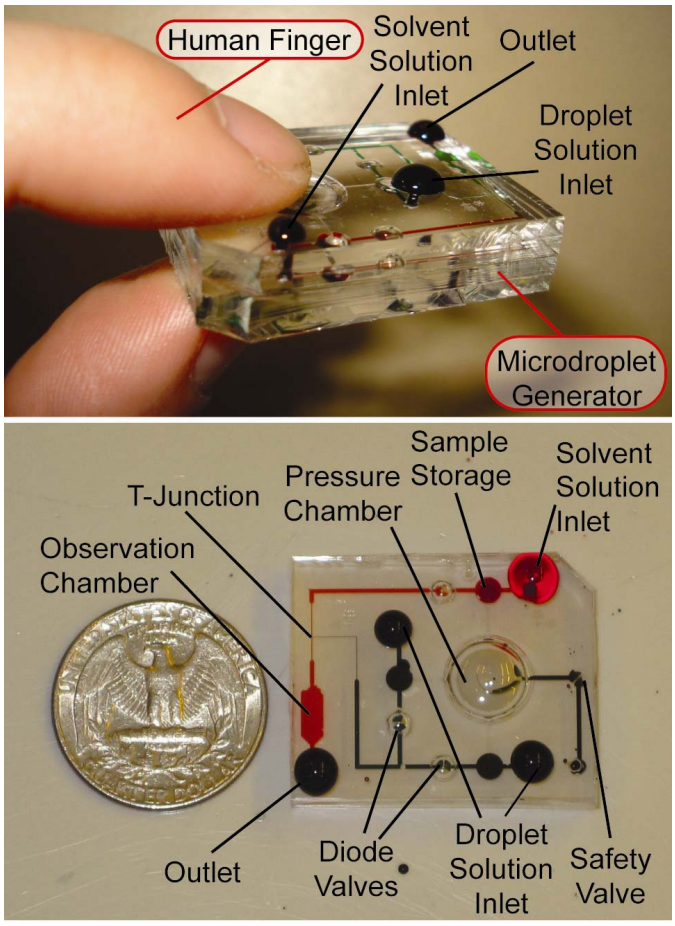

***Figure 4**: Fabricated Device (3.4cm in length, 2.75cm in width and 0.8cm in height). Channels for the solvent are showed in red, and channels for the droplet solutions are showed in blue.*

RESULTS AND DISCUSSION

The ability to generate droplets using a human finger is experimentally verified by the formation of oil droplets in water. We used Hexadecane (Sigma Aldrich, USA) as an oil droplet fluid and blue dyed water as the background water for better visibility. Dyed water mixed with Tween 20 (10% w/v, Sigma Aldrich, USA) was used to prevent the merging of droplets to form larger droplets. First, the microchannel was filled only with blue dyed water, and Hexadecane was placed onto the droplet solution port. By repeatedly conducting the push-and-release sequences, Hexadecane was introduced into the T-junction. As the flow rate of the water was faster than the flow rate of the Hexadecane at the T-junction, water cut into the path of Hexadecane, resulting in the formation of droplets of Hexadecane (**Fig. 5a**). The generated droplets were transported into the observation chamber (i.e. with decreased flow) (**Fig. 5b**). The average diameter of the generated droplets was observed to be 120µm. The variation of the droplet diameter was larger than conventional T-junction methods as expected due to the pressure differences during the push-and-release process. It is possible to increase the monodispersity of the droplets by modifying the safety valve and one-way valve designs to reduce the pressure fluctuations. Furthermore, the diameter of the droplets could be controlled by changing the channel geometry as the cross sectional area of the channel and the flow rate ratio of droplet solution and solvent solution are key control parameters [13].

Water droplets have also been successfully generated. The process started with filling devices with Hexadecane and water (dyed red for enhanced visibility) was introduced from the droplet solution inlet. Hexadecane was mixed with Span 80 (10% w/v, Sigma Aldrich, USA) to prevent the merging of the droplets. **Figure 5c** shows the formation of the water droplets at the T-junction after the same push-and-release procedure on the finger pump.

These prototype devices have been fabricated with PDMS that can degrade over time with organic solvents including Hexadecane. During experimentation, microchannel deformation was observed after a few minutes of droplet formation. During the formation of water droplets (when the system is filled with Hexadecane), degradation was exacerbated. To prevent this issue, the surface characteristics can be modified, or the materials can be changed with more durable materials.

CONCLUSION

A finger-powered microdroplet generator has been demonstrated with integrated a finger-powered pump and T-junction. Fabricated devices have produced both oil and water droplets at the T-junction section by repeatedly conducting the human finger-based push-and-release procedures on the pumping membrane. Both Hexadecane and water have been used in the current experiments for droplet generation. By modifying the channel geometry and surface characteristics, this device could be applicable to form various kinds of droplets with different

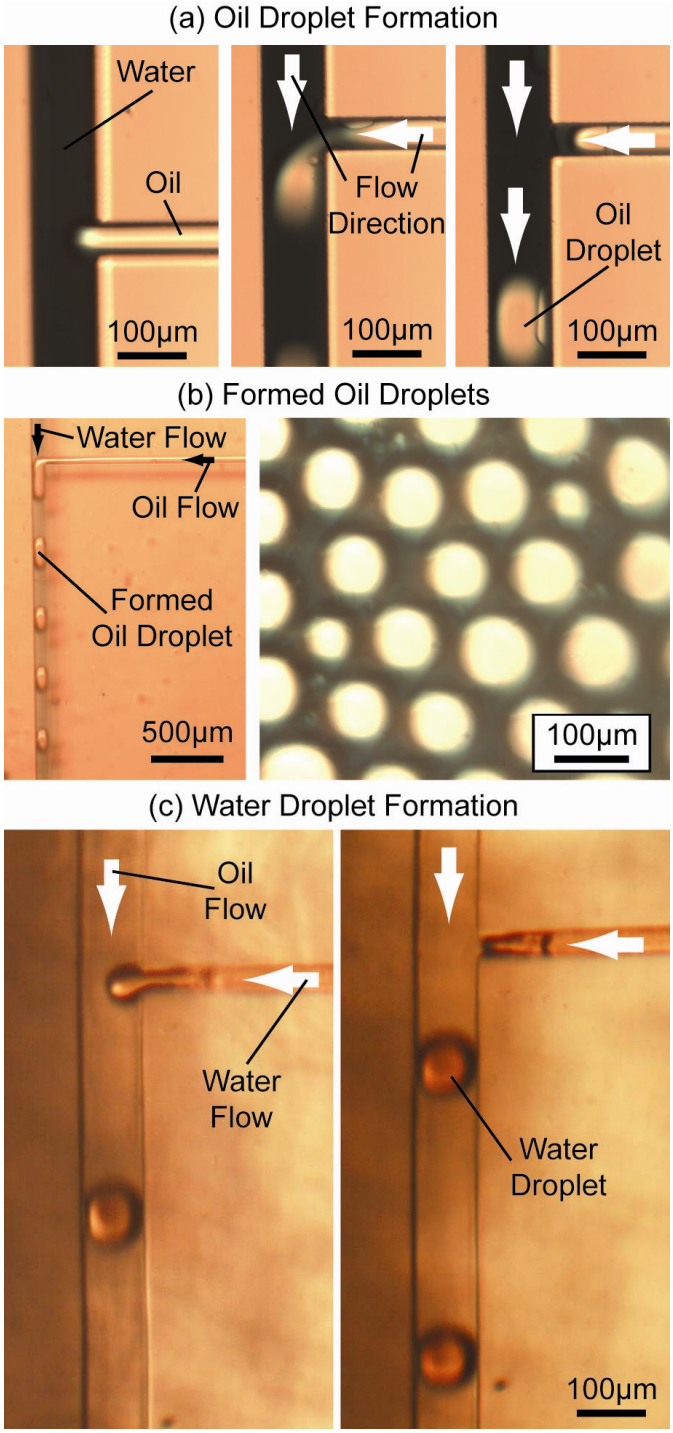

***Figure 5**: Demonstration of droplet formation process. (a) Slower oil flow was cut by faster water flow at the T-junction and formed oil droplets. (b) Formed droplets were transported into the observation chamber. Average diameter of the generated droplets was 120μm. (c) Water droplet formation with the same procedure of oil droplet formation.*

diameters. Thus, our portable and easy-to-operate droplet generator holds great potential for microfluidic applications in point-of-care diagnostics.

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