Discrete Volume Controllable Microdispenser Module

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ABSTRACT

We report a microdispenser that can meter and mix sub-nanoliter liquids in a discrete quantity. Our device is based on the structural stopping valve used in passive dispensers. A vent channel was proposed, designed for the autonomous pausing of a metered liquid segment and the seamless joining of the subsequent segments. While the previous microfluidic devices could meter only a single drop [2-4], lacking in mixing multiple segments, our approach enables the metering/mixing of different liquids in a discrete ratio. This module will find applications in bio-engineering and pharmaceutical research including large-scale cell differentiation experiment and drug discovery platforms.

Keywords: micro fluidics, passive dispenser, structural valve. lab-on-a-chip, microTAS.

1 INTRODUCTION

Like a micropipette in a macro scale experiment, fluid dispensing module is one of the vital elements of bio or chemical experiment to deliver certain volume of samples or to control sample's concentration. However, as the scale of bio-engineering platforms becomes smaller and automated with the use of lab-on-a-chip approach, it becomes challenging to deliver samples with various concentrations and volume.

Continuous active mixing at different ratios was achieved in a micro scale fluidic system, but dispensing of a small volume is inherently impossible [1]. For proper working of active fluidic system, it is necessary to fill up every channel and reservoir. Therefore, dispensing and delivering are inherently impossible. A passive fluidic system could overcome this problem, however, it need a complicated fabrication [2] or can dispense only a pre-fixed volume in a single segment [3]. This raises critical problems when a large number of pipetting is required.

We report a volume controllable microdispenser module that can meter and mix sub-nanoliter liquids in a discrete quantity. Our device is based on the structural stopping valve used in the passive dispensers [3, 4]. By adding an additional structural valve and a vent channel, we could give a controllability of metering volume to the previous passive dispenser module. The additional structural valve prevents liquid leaking through the vent channel. The vent channel prevents air trapping between metered liquid segments. We could meter several liquid segments and merge them. By this way, we could dispense certain volume of liquid with discrete manner.

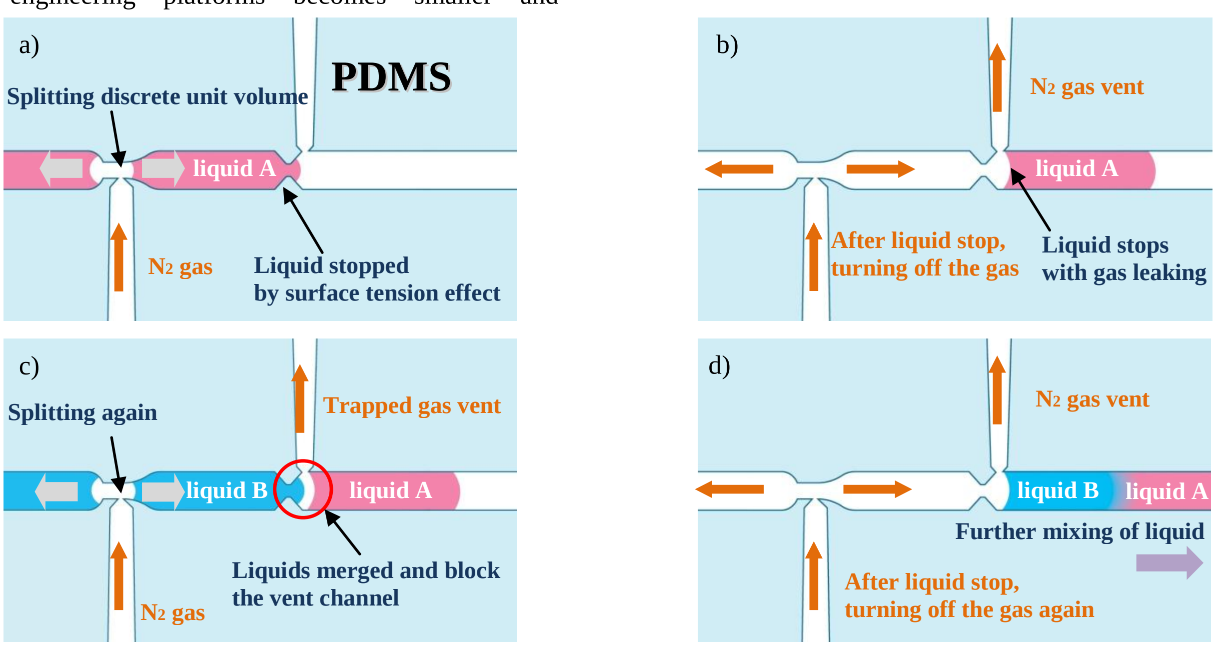

Figure 1: Schematics of device operation. Channels are made of PDMS (hydrophobic)

2 WORKING PRINCIPLE

This work is based on the principle of the structural stopping valve in the passive dispenser. Surface tension is described as

$$\Delta P = 2\sigma_l \cos(\theta_c)\left[\left(\frac{1}{w_1}+\frac{1}{h_1}\right)-\left(\frac{1}{w_2}+\frac{1}{h_2}\right)\right]$$

where, w_1, h_1 and w_2, h_2 are the width/height of the wide micro channel and narrow micro channel respectively, θ_c is the contact angle, σ_1 is the surface tension of the liquid/air interface and ΔP is the pressure required to push the liquid into the narrow channel [3, 4]. When the contact angle, θ_c is higher than 90 º, i.e., the surface is hydrophobic, the narrower channel needs a higher pressure to overcome the surface tension barrier. Also, channel geometry influences effective contact angle. Thus, by varying channel geometry and dimension, we can stop flow at a certain point necessary.

We added an additional passive valve and a vent channel essential for pausing the movement of the metered segment, and merging next ones. Figure 1 explains the sequence of the device operation driven by a pressure source. Liquid is metered by graduating reservoir, and the metered liquid is delivered by pneumatic actuation. The vent channel is narrower than the main one with the neck-shape entrance designed to effectively block the liquid flow. Thus, the liquid segment flows only through the main channel while the pressurizing gas escapes thorough the vent channel. The liquid segment stops at the branch point waiting for the next one to join. Through the repetition of the sequence, mixing ratio can be controlled in a discrete manner.

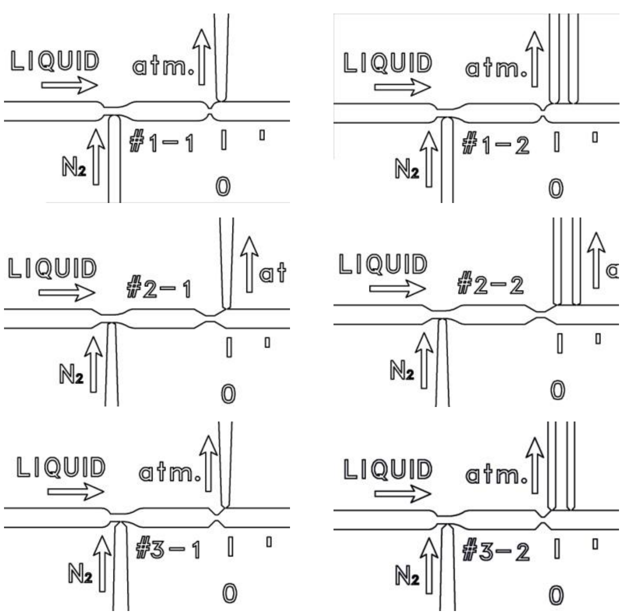

Figure 2: tested design valves shape and dimension was varied. Design number 1-1 showed best performance

3 FABRICATION

Hydrophobic channels were fabricated with PDMS. As PDMS is inherently hydrophobic, we could easily make the dispenser module by the replica molding process without any hydrophobic surface treatment. The mold was made of AZ4620 photoresist (10 μm thick) using photolithography. Then the channel was replicated from the mold and bonded onto a PDMS-coated glass slip by oxygen plasma treatment.

Various designs were tested and optimized to obtain the best working module (Figure 2). The round shape structural valves (1-1 & 1-2) showed better blocking performance than the linear shape valves, but were difficult to fabricate reproducibly. Additional vent channels (1-2, 2-2, & 3-2) did not affect the performance a lot.

The fidelity of fabrication was important. Little difference from the design could cause malfunctions. For example, the fidelity of the lithographic process was critical in controlling channel geometry accurately and preventing a malfunction of devices. Figure 3 explains the failure cases when the device was not fabricated as designed. The neck shape of structural valve easily fabricated wider than designed, and as a result, the wider passive valve failed to block the liquid effectively.

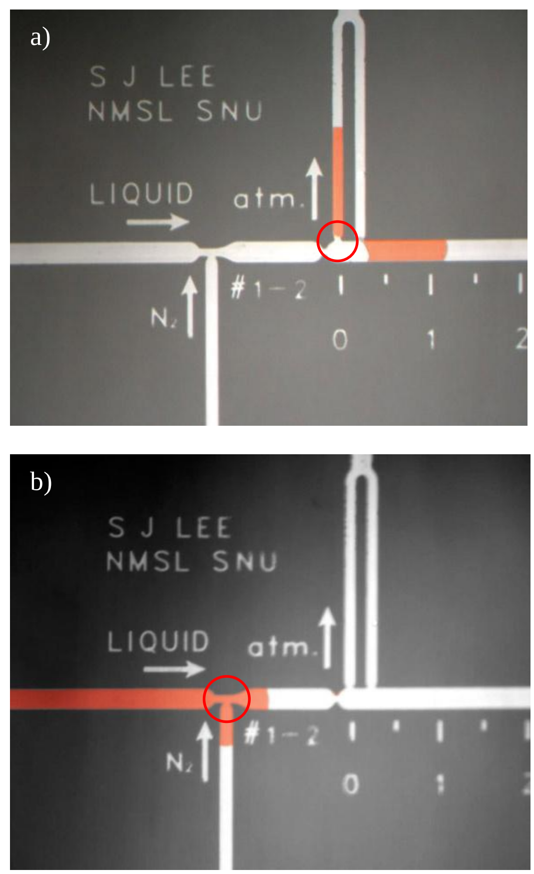

Figure 3: Failure cases: a) liquid blocks vent line; b) liquid blocks N_2 line (Liquids colored using computer graphics)

4 EXPERIMENTAL RESULTS

We successfully demonstrated the volume controllable fluidic dispenser modules. Figure 4 shows the working sequence of the module that operates reliably for many runs of experiments. In Figure 4 (a) it is observed that the liquid segment was stopped by surface-tension effect. This filling sequence was followed by pressurizing the N_2 line with a pressure higher than in the liquid line. The pressure made the segment start moving towards the outlet, but the segment stopped at the branch point because of the vent channel (Figure 3 (b), (c)). When this sequence was repeated the approaching segment joined the stopped one, and proceeded further automatically (Figure 3 (d), (e), (f)). By repeating this series of operations with different liquids, certain volume of mixture can be dispensed at a specific ratio.

Evaporation of liquid was observed during the experiment. The miniscule amount of liquid quickly evaporated because of the porosity of PDMS and high surface to volume ratio on microscale. The loss of liquid by evaporation is serious when the dispenser needs to be accurate. This problem could be overcome by non-porous coating of channel. For instance, parylene or Teflon could be available. Otherwise, this device can be fabricated with totally different materials such as glass since the basic working principle is universal.

5 DISCUSSION AND SUMMARY

It should be emphasized that the key function of the device comes from the operation with the vent channel and the surface wettability. Since the vent channel had a structural valve which is always in an off condition, liquid could not leak through the vent channel. Pressuring gas, on the other hand, could escape through the vent channel without any resistance. Thus the merging of metered segments was allowed without air trapping between them. By repeating this dispensing sequence, we could control the dispensing volume of liquid in a discrete manner without any bubble trapped.

We designed and fabricated a volume controllable micro dispenser module. The operation of the module was demonstrated. Essentially our device was based on the passive dispenser, but key modifications were added. The vent channel with a structural valve enabled a controllable dispensing of liquid volume and removal of bubbles. While the previous dispenser could meter only a pre-fixed volume of liquid, our device can digitally control the dispensing ratio during operation.

This paper also dealt with issues found during the study of the fabricated devices. The fabrication had to be very accurate and repeatable. When the device was fabricated with small error, correct function was not guaranteed. Especially, high quality photolithographic process was crucial for device performance. Liquid evaporation was occurred at a faster rate than expected and degraded the accuracy of dispensing.

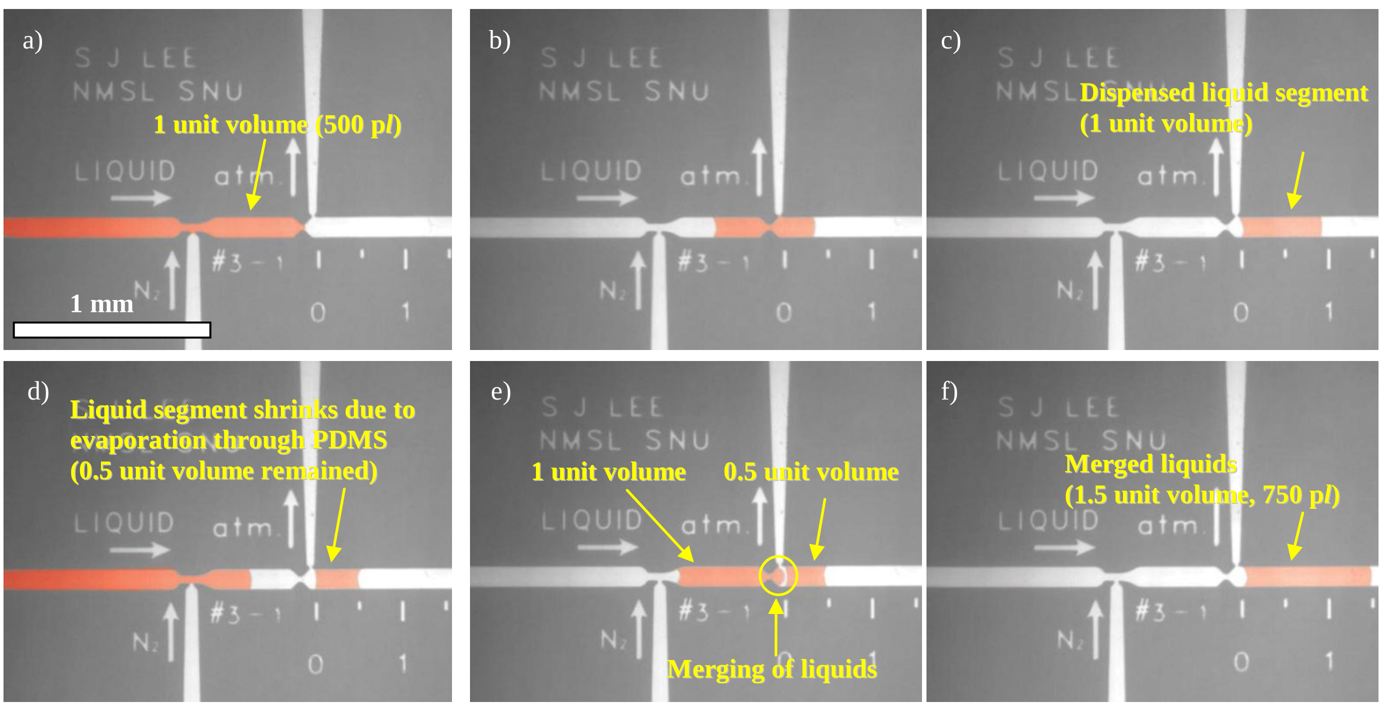

Figure 4: Microphotograph of volume controllable microdispenser: a) reservoir filled; b) splitting liquid column with pneumatic actuation; c) exact stopping right after passing vent channel; d) second reservoir filled, initially dispensed liquid drop does not move; e) merging two liquid drops with pneumatic actuation; f) exact stopping right after passing vent channel

Our dispensing module will find applications in a lab-on-a-chip and micro-TAS systems. Especially, when a large number of pipetting is required, for example, in a large-scale cell differentiation experiment and pharmaceutical research, this module will be useful. Unlike conventional microfluidic mixing modules that offer fixed ratios, our dispenser module can vary the mixing ratio during operation like a micropipette in macro scale experiment.

Acknowledgement

This research was performed for the Intelligent Robotics Development Program, one of the 21st Century Frontier R&D Programs funded by the Ministry of Commerce, Industry and Energy of Korea.

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