ABSTRACT

We designed and fabricated a droplet division device for a wide range dynamic volume ratio and size control of microdroplets. Water-in-oil microdroplets generated at cross junction were separated using active flow resistance control of a Y-shaped droplet division device. Flow resistance of each outlet channel is controlled by two horizontal pneumatic valves formed at the downstream of the bifurcating microchannel. Available volume ratio of daughter microdroplets ranged from 1:1 to 1:145. Size control from about 9 pl to 1 nl was also realized. The generation rate is constant even if the droplet sizes are different in three digits.

KEYWORDS: Microfluidic, Droplet, Division, Pneumatic valve

INTRODUCTION

Microdroplet technologies are effective methods to control small samples [1], and they have been developed in recent years to apply to chemical reaction and encapsulation of a single cell [2]. In order to maximize their advantages, volume and size control of microdroplets is one of the important issues. If two types of volume controlled microdroplets are generated and merged by precise microfluidic control, a series of microdroplets with various concentration ratios can be generated in a microfluidic device. Efficient chemical synthesis of various compounding ratios useful for drug discovery can also be performed by integrating above microfluidic devices.

Microdroplet generation at cross junction is a well-known method [3]. However, there is a limit in generation of microdroplets of different volume and size by control of two-phase flow rates. Low generation rate is another disadvantage. Therefore, our group has studied about droplet division devices to obtain wide range volume and size control and high throughput of droplet generation. Using two types of cascade multi-stage separation devices with shifted-pillar structure and asymmetric wall structure, microdroplets of different volume ratio could be generated [4]. However, the range of volume and size of microdroplets was limited in the fixed structure. On the other hand, horizontal pneumatic microvalves which can widely control flow resistance of microchannels were developed in PDMS (polydimethylsiloxane) microfluidic devices and systems [5]. In this paper, we present a microfluidic device which can control volume and size of microdroplets in a wide range. By integrating bifurcating microchannel with pneumatic valves, a wide range dynamic volume ratio and size control and high throughput generation of microdroplets were achieved.

CONCEPT

Figure 1 shows the principle of microdroplet division by flow resistance control in the bifurcating microchannel. When microdroplets are divided in a bifurcation point, the volume ratio of two daughter droplets depends on the downstream flow resistance. Since the flow rate of the channel with higher flow resistance is lower than that of the other channel, the size of daughter microdroplets becomes smaller. Therefore, if the flow resistance could be precisely controlled, it is possible to divide microdroplets in any ratios.

Figure 1: Controllable microdroplet division in bifurcating microchannel using a change in flow resistance of downstream

R₁, R₂ : Flow resistance
V₁, V₂ : Droplet volume

R₁ = R₂
V₁ = V₂

R₁ > R₂
V₁ < V₂

R₁ >> R₂
V₁ >> V₂

Figure 1: Controllable microdroplet division in bifurcating microchannel using a change in flow resistance of downstream
As shown in Figure 2, two horizontal pneumatic valves (Valve I and Valve II) are formed at downstream in the bifurcation point of the Y-shaped separation part to control the flow resistance of microchannels. When air pressure is applied to one horizontal pneumatic valve, flow resistance becomes large since the width of channel around the valve becomes narrow. Each pneumatic line can operate independently and both flow resistances in Channel I and Channel II can be individually controlled. Thus, original microdroplets generated at cross junction can be divided into two different sizes at the bifurcation point.

**EXPERIMENTAL**

Figure 2 also shows total design of the microdroplet division device and detailed sizes of each part; a droplet generation part, a division part, and an observation part. Width of the cross junction becomes narrow from 100 µm to 50 µm to easily obtain water-in-oil microdroplets. Since the bifurcation point has the nozzle shape instead of a simple cross junction, the original microdroplets are located in the center of the inlet microchannel. As a result, original microdroplets are stably introduced and divided at the bifurcation point. Since thickness of deformable membranes of the valves is designed as 30 µm, sufficient deformation is obtained by the valve drive. In order to observe divided microdroplets, the observation parts of 150 µm in width are formed at each outlet channel.

The device was fabricated by PDMS replicated from a SU-8 (SU-8 3050, MicroChem) mold. The mold pattern was obtained by single-step photolithography, and the height of all SU-8 structure was about 95 µm. After PDMS replicating from the SU-8 mold, the structure of PDMS was bonded with PDMS coated glass substrate by O₂ plasma treatment. In order to obtain more flexible PDMS structure, resin and curing agent were mixed in 15:1 ratio.

Deionized water was used as a water phase while salad oil was used as an oil phase. Water and oil were introduced by syringe pumps (KDS200, KD Scientific), and pneumatic pressure was controlled by a pressure regulator (IR2000-02BG, SMC). The droplet division was captured by a high speed camera (FASTCAM-EO 32KC, Photron) and droplet sizes were calculated by pixel counting.

**RESULTS AND DISCUSSION**

Original droplets were generated with about 1 nl in volume and around 130 µm in size under water and oil flow rate of 1 µl/min. To control the volume ratio of daughter droplets, pneumatic pressure of Valve I was changed from 0 kPa to 155 kPa. Microdroplet division results with different applied pressures are shown in Figure 3. When the pneumatic pressure was 0 kPa, original microdroplets were divided almost half and half. With increase in pneumatic pressure of Valve I, size of microdroplets in Channel I decreased. A change in ratio of droplet volume in Channel I and Channel II VS pneumatic pressure of Valve I is shown in Figure 4. Stable division was obtained under applied pressure up to 150 kPa. At 150 kPa, a maximum volume ratio of 1:145 was achieved. When the microchannel was almost closed at around 155 kPa, original droplets flowed into Channel II. Figure 5 shows the volume of microdroplets in Channel I (left half) and Channel II (right half) under different applied pressure. Constant microdroplet generation of approximately 800 drops/min with volume from 8.62 pl to 1.25 nl was obtained.
CONCLUSION

We successfully achieved a wide range volume ratio and size controlled division of microdroplets using deformable horizontal pneumatic valves. Stable division was obtained under applied pressure from 0 kPa to 150 kPa. Available volume ratio of daughter microdroplets ranged from 1:1 to 1:145. Size control from about 9 pl to 1 nl was also realized. For our next step, total microfluidic systems of droplet merging and sorting integrated with the proposed division device is under investigation.

ACKNOWLEDGEMENTS

This work is partly supported by Japan Ministry of Education, Culture, Sports Science and Technology Grant-in-Aid for Scientific Basic Research (S) o. 23226010, and the authors thanks for anotechnology Platform of Waseda University for their technical assistances.

REFERENCES