분지 유로를 이용한 미세유체장치 내의 액적 생성

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Droplet generation in the microfluidic device with branched channel

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Introduction

The droplet generation and manipulation in microchannel flow has been studied in the past decade. The advantages of using microchannel flow are to manipulate very small volumes (pico/nanoliter size) and to investigate the individual motion of the drops fabricated by the order of tens and hundred micron size structures [1,2].

For example, nanoliters of reagents can be removed (through breakup) from a droplet or can be added (through droplet coalescence) leading to desired chemical reaction rates and times. It is necessary to generate monodispersed droplets for precise control of the volume as a droplet-based reactor.

The design of the channel geometry is critical to control the forces that generate, transport, split and fuse droplets. Several designs have been suggested for generation such as T-junction and co-flowing streams of immiscible solutions[3,4]. The current design is often empirical and not found on a rigorous study of the flow characteristics.[5]

In this study, we generate the monodispersed droplet in the continuous phase using branched channel geometry such as cross shape and 3-way branch, and investigated the drop formation mechanism.

Experimental

Microchannels were fabricated by molding polydimethylsiloxane (PDMS, Sylgard 184, Dow Corning) upon a silicon wafer containing positive-relief channels patterned in SU-8 photoresist [6]. The microchannel attached to slide glass spin-coated with PDMS so that the microfluidic device was manufactured as 4-PDMS wall channel. Though PDMS-glass hybridized microdevices were broadly used, it is not adequate for aqueous droplet generation due to hyrophobicity difference (Fig 1a,b). The plasma sterilizer (PDC-32G, Harrick) was used to attach the PDMS coated glass and PDMS channel. After plasma treatment, the microfluidic device was cured at 120°C to prevent wetting. If the oil and water were inputted immediately after plasma treatment, the water was wetted on the bottom surface (Fig 1c).

The geometry of microchannels were branched shape. In cross shape case, the width of channel was 200μm and we observed the droplet generation at junction region (200μm x 200μm) and the downstream. The continuous phase (oil) was inputted through top and bottom channels and the dispersed phase was flowed from left side channel. In 3-way branched shape case, the width of mainstream channel was 225μm and those of three branched channels were 75μm. The angle from main stream channel to branched channels were 60°, 90°, 120°. The depth of all channels were 75μm measured by confocal microscope (OLS 3000, Olympus).

The flow rates of the liquids were adjusted by syringe pump (KDS-101,110, 210, KD Scientific). Motion of droplet in the microchannel were observed with High speed camera (ultima512, Photron) mounted on optical inverted microscope (IX-71, Olympus). Viscosity of the liquids were measured with rotational rheometer (ARES ,TA Instrument). The viscosity of continuous and dispersed phases were 52 cp and 1 cp. The experiments were performed at room temperature.

Result and discussion

Monodispersed drops were generated by hydrodynamic focusing flow in cross shape channel(Fig 2). As the sheath flow rate (oil) was increased, the width of center flow(water) was narrower. There were two mechanism of droplet generation : dripping(Fig 2a) and jetting(Fig 2b).

The dripping produces droplets close to the junction region, analogous to a dripping faucet. Droplets produced by dripping are typically highly monodispersed (ex: experimental condition- oil flow rate 5μl/min, water flow rate 2μl/min, Mean droplet diameter=110.5±5.4μm, Droplet generation rate=18.5Hz). The droplet was grown and pinched-off. In the pinched-off process, the dispersed phase was slightly retracted even though it is Newtonian fluid.

The jetting produced a long jet that extends three or more of channel diameters to downstream where it breaks into droplets. The jetting formation might come from the viscous stress of the continuous fluid, whose viscosity is greater than that of the dispersed fluids in this experiment. The droplets were generated by Rayleigh-Plateau instability at downstream. The jetting also generated the monodisperse drops (ex: experimental condition- Oil flow rate 20μl/min, Water flow rate 10μl/min, Mean droplet diameter=195.4±8.8μm, Droplet generation rate=211.1Hz)

To compare both mechanism, the mean droplet sizes were plotted with total flow rate; continuous phase and dispersed phase (Fig 3). The droplet by jetting was larger diameter and generated faster compared by dripping. It may come from several break-up point by instability in jetting process(Fig 2).

Monodisperse droplet also generated in 3-way branched channel (Fig 4). When the inputted (dispersed phase) flow rate is low, the droplet was generated at the junction region and the size was small (Fig 4a). When the mainstream flow rate was increased, the droplet was generated at the downstream (Fig 4b,c). The generated droplet formed several shape depending the flow rates (Fig 5). As we increase total inputted flow rate, the droplet size was decreased and generation frequency is increased. We expect that droplet size and generation frequency can be controlled by flow rate of continuous and dispersed phase flow rate.

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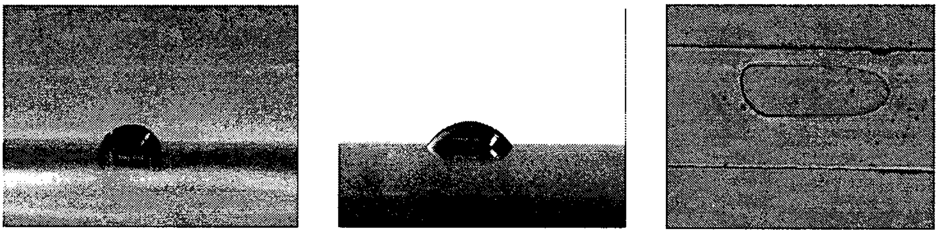
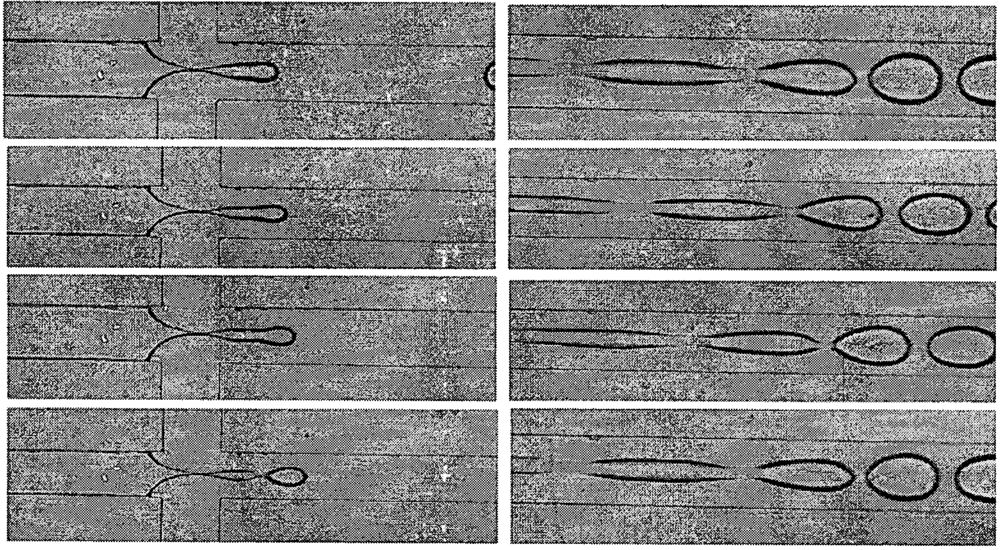


(a) (b) (c)

Figure 1. Water drop on the surface (a) PDMS (b) glass (c) wetted in microchannel



(a) (b)

Figure 2.Droplet generation by (a)dripping and (b)jetting mechanism; time interval between each image is 1/600sec

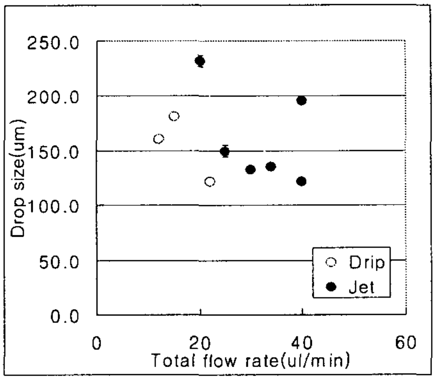
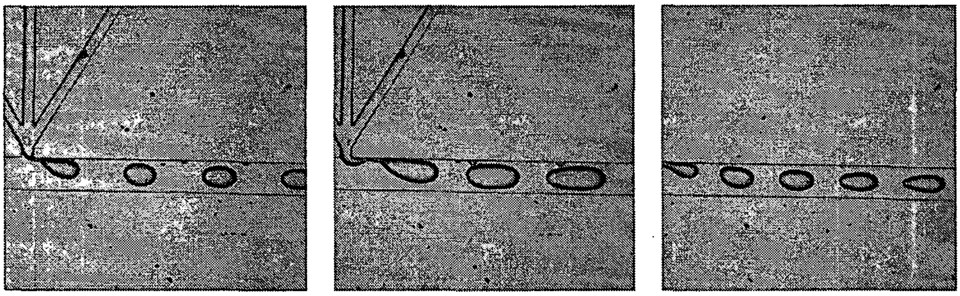


Figure 3. Droplet size versus total flow rate by dripping and jetting mechanism



(a) (b) (c)

Figure 4. Droplet generation in 3-way branched channel at (a) junction (b) junction and downstream (c) downstream

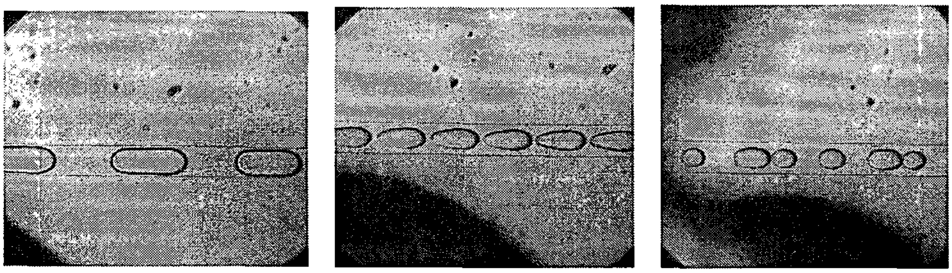


Figure 5. Various shape of droplet generated by flow rate control