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Novel system for fabrication of pico-liter droplets with high viscosity

高粘度液体の射出を可能にするピコリットル液滴生成技術の開発

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1. Introduction

Using the inkjet technique, we developed observation and measurement systems for micro liquid dynamics that could be used for various observation tasks, e.g., capturing time-lapse views of the wetting and penetration process of a liquid on various substrates [1,2]. During such observations, managing the purity of the landing point of the droplet on the substrate is important. We designed the observation system based on so-called on-demand inkjets, wherein the timing of droplet ejection can be controlled freely by the electrical signal generator. The most famous application of this type of inkjet is in consumer printers. To ensure easy and accurate printing, inkjet printers only allow the use of inks with well-controlled properties, such as surface tension, viscosity, and contained particle size. For liquid dynamics analysis, the microdroplet fabrication device requires a wide selectability of sample liquids. In particular, droplets with a high viscosity of ~100 mPa·s need to be generated. With our previous on-demand inkjet, we were able to eject droplets like ethylene glycol with a viscosity of ~20 mPa·s. In this work, we constructed a novel on-demand system that allows the generation of microdroplets with high viscosity.

2. Our previous system for fabrication and observation of pico-liter droplets

A glass capillary tube with a 30-µm-diameter fine tip was used as the nozzle for generating droplets in our inkjet device. In our previous system, we used two small piezo actuators and the belly of the capillary tube was sandwiched between the actuators. The sample liquid in the glass tube is ejected under momentary pressure by applying an electrical spike signal to the two actuators simultaneously, and the small amount of liquid ejected from the nozzle becomes a droplet owing to

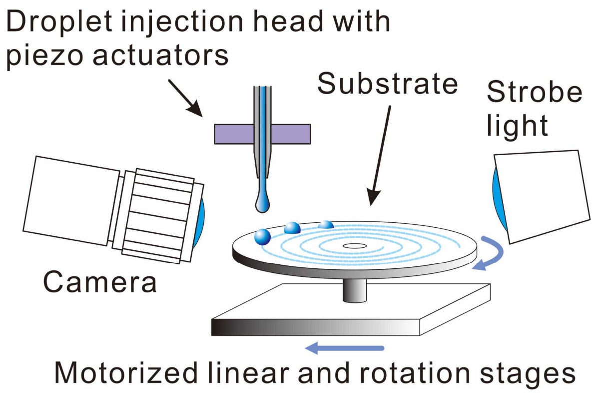

Fig. 1 Schematic view of our previous system for observation of the dynamics of pico-liter droplets on a substrate. The landing spots of the droplets make a spiral curve because of the controlled motion of the substrate. We can obtain a series of images of droplet shapes for a long time.

its surface tension. We use the stroboscopic technique to observe the droplet dynamics with high temporal and spatial resolutions of ~0.1 µs and ~1 µm, respectively. To ensure that the droplets always land on a fresh part of the substrate, the substrate was

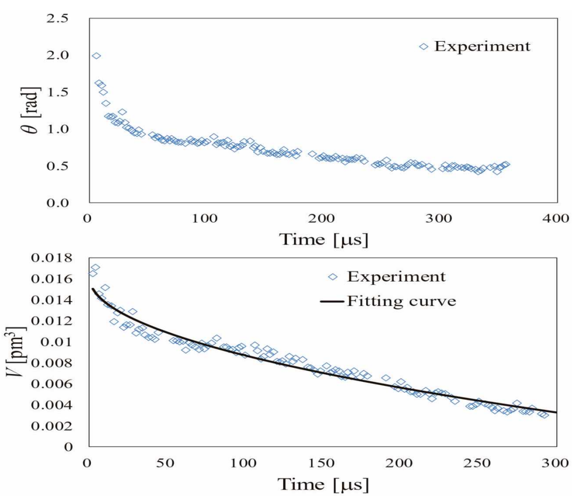

Fig. 2 Penetrating behavior of water droplet on porous glass with a porosity of 49% and pore size of 50 nm [3].

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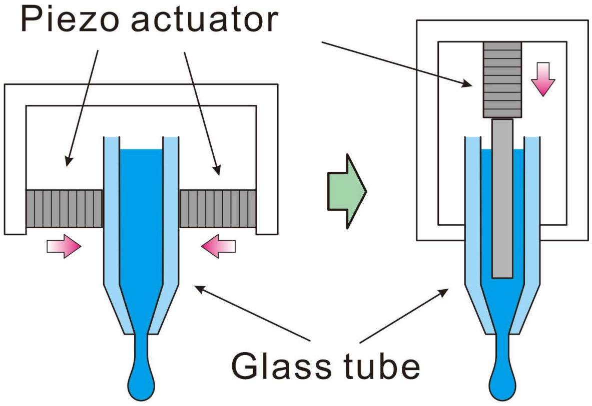

Fig. 3 Schematic images of (left) non-contact head and (right) direct push head. The same tip size, 30 μm, can be used for the glass tube of both heads. In addition, the same electric circuit can be used for the actuators for both systems.

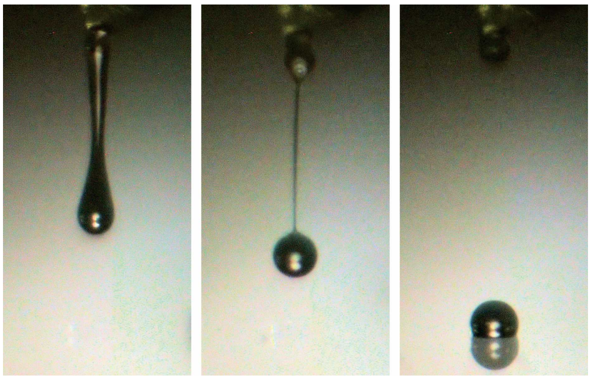

Fig. 4 Stroboscopic and microscopic images of an 80 wt% glycerin droplet during ejection and landing on a flat glass plate. The viscosity of the sample was 60 mPa·s at 20°C. The droplet diameter was ~50 μm.

moved spirally using a motorized linear and rotating stage. **Figure 1** shows a schematic of our fabrication and observation system. The droplet behavior on a porous glass substrate was successfully characterized, as shown in **Fig. 2** [3]. The fitting curve in **Fig. 2** shows the result of a calculation based on our originally constructed penetration model.

3. New System for highly viscous liquids

Our previous fabrication system for picoliter droplets has the remarkable feature of non-contact droplet generation, wherein we do not have to consider the sample liquid in the glass tube nozzle. The ejection pressure on the liquid is applied from outside the glass tube. This pressure is sufficient to generate low-viscosity droplets, such as ethylene glycol with a viscosity of 16 mPa·s at 25°C. However, ejecting and fabricating droplets with a viscosity higher than 20 mPa·s using this method is difficult. To observe the dynamics of droplets of liquids with higher viscosity, we designed a new method to eject liquid from the tip of the glass nozzle, in which ejection is caused by directly applying the spike-like pressure to the liquid. **Figure 3** shows schematic images of our previous and novel ejection heads. In the new head, the sample liquid is pushed by a thin metal rod attached to a piezo actuator, and the pressure applied to the liquid is determined by the movement of the actuator. Although this head system does not allow for non-contact droplet fabrication, various rods can be used for pushing the liquid, such as stainless steel, ceramic, or glass. Moreover, no consideration has to be given to sample contamination.

With this new head, we succeeded in generating microdroplets with a higher viscosity than that possible our previous system. **Figure 4** shows microscopic images of 80 wt% glycerin droplets with a viscosity of 60 mPa·s. As shown in the middle graphic in **Fig. 4**, a viscous droplet in flight leaves a trail similar to a spider thread, which can be attributed to the viscosity of the liquid. The time required to break off the liquid jet ejecting from the tip of the nozzle is longer because of the higher viscosity or lower surface tension. We know that glycerin shows the behavior of a Newtonian liquid whose viscosity is independent of the shear rate and is suitable as a sample for an inkjet system except for its high viscosity. In the next step, we will attempt to determine the maximum viscosity at which droplets can be generated and to check the applicability of our new system to non-Newtonian liquids.

References

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