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Study of microdroplet generation by ultrasonic propagation
超音波伝達による微小液滴形成の研究

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1. Introduction

Inkjet printing technology is now widely applied for the micro-manufacturing process of soft matters, and the variety of the material is being expanded for the future use of the inkjet emission. The major method of the fabrication of the micro liquid droplet is the on-demand type, in which the pulsed pressure is applied by the piezo-actuator or the thermal stimulation on to the surface at the edge of the nozzle.

We have recently developed a new type of the inkjet nozzle made of a glass capillary. The lateral surface of the nozzle is pressed by the piezo-actuator and the elastic pulse thus applied to the nozzle propagates toward the edge, increasing its amplitude along the taper of the nozzle. A liquid droplet is launched by the radiation pressure of the elastic wave through the reflection at the surface.

The accuracy of the positioning and the reproducibility of the inkjet emission depend on the stability of the above dynamic processes. In addition, the formation of "satellites" is a serious problem in the industrial inkjet system, which are the small liquid particles accompanying the emitted main droplet. They might pollute the targets and nozzles, and do harm to the accuracy and the stability of the droplet emission.

Some physical phenomena are considered to be mainly responsible for the formation of satellites. One is a break-up of the tail of the main droplet. In the conventional drop-on-demand type inkjet system, a thin liquid tail follows the main droplet, which is unstable with respect to the fluctuation in the thickness and spontaneously breaks up to form the small satellite particles (**Fig. 1**).

Another is the droplet generation at the meniscuses. When the wetting properties such as the wetting angle is not homogeneous at the touching line of the liquid and the nozzle, the liquid forms local meniscuses, where the satellites are known to be often generated. The wetting property on the nozzle surface is carefully controlled in the industrial inkjet system, however, the pollution of the nozzle easily changes the wettability.

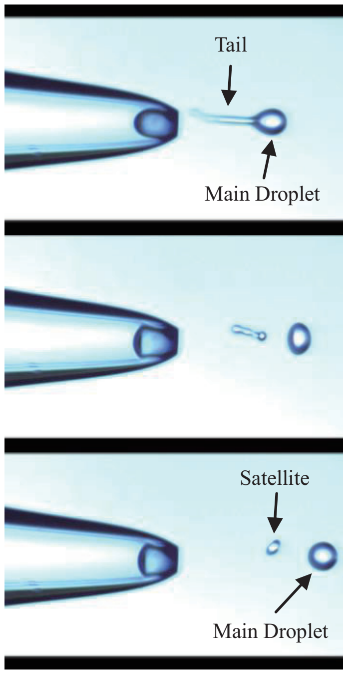

Fig. 1 Satellite formation of drop-on-demand type inkjet. The tail of the main droplet breaks up into a small liquid particle.

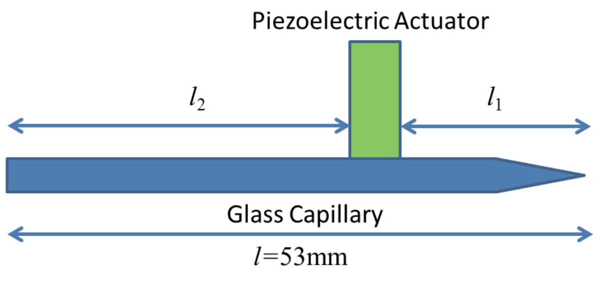

Fig. 2 Schematic Picture of drop-on-demand type inkjet system.

2. Liquid particle emission by elastic wave

For the process of the droplet and satellite formation, the acoustic propagation takes an important role. The main droplet is generated by the acoustic pulse and the vibration of meniscuses often develops to form satellites. In this study, we observed the propagation of the acoustic pulse applied by a piezo actuator, and the normal mode oscillation of the liquid at the tip of the inkjet nozzle. This study provides us with fundamental information of the acoustic and wetting effect to the stability of the droplet formation.

We used the original inkjet equipment system [1], which is schematically shown in **Fig. 2**. The inkjet nozzle consists of the piezo-actuator and the glass capillary. This inkjet is chemically tough enough to handle strong acids, alkalis, and organic liquids. The inner radius of the nozzle orifice is 15 μm.

We used the strobe method to observe the droplet and inkjet behavior with high temporal resolution. We used video microscope (Keyence) and Nano-Pulse Light (Sugawara-Lab. Inc.) which illuminates for only 100 ns. The strobe light is focused with a pair of plano-convex lenses. This system enables the dynamic observation both with the temporal resolution better than 1 μs and spatial resolution higher than 1 μm.

3. Results and Discussion

Since the acoustic pulse propagates with the sound velocity of the media, it takes finite time to emit the liquid droplet after the elastic pulse was applied on to the position apart from the edge of the nozzle. We changed the distance between piezo and nozzle orifice, and measured the delay of the droplet emission to the piezo trigger, and the result is shown in **Fig. 3**.

From the gradient of the data in Fig. 3, the pulse velocity is estimated to about 3000 m/s, while the sound velocity in sample water is about 1500 m/s. It shows that the elastic wave propagating the momentum to emit the liquid particle is not confined only in the cylindrical liquid but may include the elastic deformation of the glass nozzle. Actually, the speed of sound in glass is 5600 m/s for the longitudinal wave and 3600 m/s for the shear wave. Therefore, the droplet emission is suggested to be due to the shear wave in the glass nozzle.

We also observed the behavior of liquid on the nozzle orifice. After the emission of the main droplet, the liquid on the nozzle orifice shows oscillatory motion and this oscillation sometimes develops to form satellites. We used water and ethylene glycol as samples and observed the dynamic behavior of the surface with the method described above.

The motions of the liquids on the nozzle orifice are shown in **Fig. 4**. We can see the motion of the surface of the water mainly takes place inside of the nozzle for 100 μs after the emission, and then the surface oscillates outside the nozzle. The oscillation outside of the nozzle is unstable and may easily break up to form the satellites.

On the other hand, the oscillation of ethylene glycol is relatively stable for long period after the emission. The origin of the oscillation is inside of the nozzle. The difference between these dynamic behaviors is plausibly caused by the difference in the wetting property of the liquid and the nozzle surface. We are now analyzing the oscillation modes of the surface and trying to relate to the actual propagation mode of the elastic waves. It should also be considered that the surface tension and the shape of meniscus may contribute to the oscillation mode, and the present experimental method would be a useful tool for the purpose.

References

1. H. Kutsuna and K. Sakai: Appl. Phys. Express **1** (2008) 027002.
2. H. C. Lee: IBM J. Res. Dev. **18** (1974) 364.
3. W. T. Pimbley and H. C. Lee: IBM J. Res. Dev. **21** (1977) 21.
4. Lord Rayleigh: Proc. London Math. Soc. **10** (1878) 4.
5. V. G. Levich: *Physicochemical Hydrodynamics* (Prentice-hall Inc., N. J., 1962)

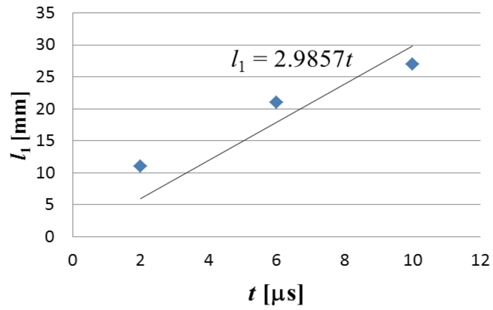

Fig. 3 The distance between piezo and nozzle orifice l_1 versus the interval between piezo trigger and droplet emission t.

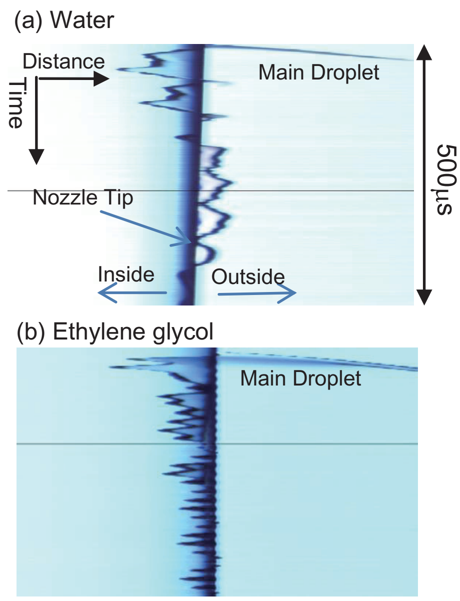

Fig. 4 Motion of liquid on the tip of the nozzle.