FINE-Printhead for Sub-picoliter Droplet

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Abstract

The inkjet printer has become very popular these days. Most of the printers used in homes and offices are capable of producing photo quality printouts. The droplet volume of these printers lies in the range of 1 to 5 picoliter. Although the inkjet technology has the ability to produce even smaller droplet, sub-picoliter droplet, the requirement for the stable ejection and the system design to meet those requirements was not studied in detail. The object of this study is to clarify the configuration requirements of the stable ejection of the fine sub-picoliter droplets and realize those requirements by building prototypes.

Downsizing of the Inkjet Droplet

Downsizing of the inkjet droplet was accelerated first when the personal computer started to handle the digital graphic data and printing photo in home has become the reality. Needs for smooth and grainless photo quality printouts have emerged as a result. In the late 90's, the printer with diluted ink and droplet volume under 10 picoliter appeared on the market and has become popular [1]. Next came the demand for wide color gamut and diluted ink has been replaced by special color inks like red, green and blue. Further downsizing of the droplet to achieve grainless print outs without diluted inks become necessary. The target has set around 1picoliter which produce 20 micron dot on the media.

On the other hand, digital fabrication of the fine structures like the printed wire or the color filter for the LCD using inkjet technology is drawing attention recently because of a number of attractions like low capital investment, water based environment friendly process, high flexibility data handling etc.. Printed line of several microns in width is necessary in this case. Namely, the droplet volume under 1 picoliter will become necessary.

The object of this study is to clarify the configuration requirements of the stable ejection of the fine sub-picoliter droplets and realize those requirements by building prototypes.

Physics of the fine droplet ejection

The key factors preventing the stable ejection and precise deposition of the fine droplets are the increase of the resistance inside and outside the nozzle. Inside the nozzle, the smaller orifice diameter leads to the higher flow resistance of the ink. Once outside the nozzle, the air resistance of the flying objects increases proportional to their diameter divided by their mass.

Fig. 1 shows the flying distance of the droplets having various volume and initial velocity as the function of time. The trajectory of the 0.2 picoliter droplet having 10 m/s initial velocity curves near the 1mm distance, while on the other hand the trajectory of 5 picoliter droplet with same initial velocity is almost linear. The difference of the flying time between two droplets leads to the misalignment of the printed dots because the printhead have relative velocity to the media.

One solution to this problem is to set the media closer to the printhead. But it is not applicable to the flexible media like paper. So increasing the initial ejecting velocity becomes very important to achieve precise deposition of sub-picoliter droplet. The trajectory of 0.2 picoliter having 12 m/s ejecting velocity is shown in fig. 1. But, ejecting the droplet at higher velocity is not the easy task. As mentioned before, as the orifice becomes smaller the flow resistance inside the nozzle becomes larger. The new design of the ejection system is required to overcome this problem.

Another concern about the stable ejection of fine droplets are the misdirection of droplets caused by external force in the plane perpendicular to ejecting direction; i.e. the face of the printhead. Asymmetry of nozzle geometry or fluid property can be the source of the external force to the droplet.

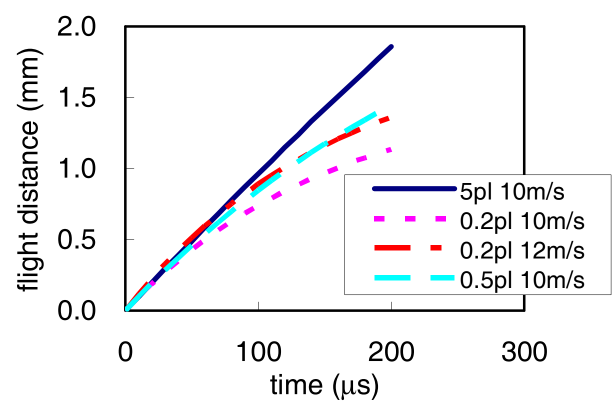

Figure 1. *Flight distance of the droplets.*

Design of the ejection system

Design of the ejection system for high ejection velocity can be classified into two groups: High propulsion power design and high power transfer design. In the case of the bubble jet, the propulsion power is the pressure of the boiling bubble. Higher propulsion power can be achieved by large area heater or application of the pre-heating pulse to the heater to hold the high pressure after the boiling by pre-heating the ink in the vicinity of the heater. These issues have been argued already so will not be argued in detail in this paper.

High power transfer design can be achieved by reducing the flow resistance ratio of outlet resistance and inlet resistance. Increasing the inlet resistance leads to the increase of the total resistance of the nozzle, which cause the decrease of the repetition frequency, so it must be combined with the reduction of the flow resistance through the outlet. The resistance of the nozzle outlet is defined by the cross-section and the thickness of the outlet. For producing 5 picoliter droplet, the diameter of the orifice is around 15 microns and the thickness is about 10 microns. To reduce the resistance, reducing the thickness of the outlet to 5 microns and changing the shape to conical outlet have been chosen.

The effect of the asymmetric nozzle geometry and the asymmetric flow near the orifice has been studied for thick and thin outlet by 3D flow simulation. It is found that the direction of the droplet is affected largely in the thinner outlet. So the requirements for stable ejection and precise deposition of the sub-picoliter droplets are described as follows;

a) Thinner outlet thickness
b) Conical outlet shape
c) Precise processing of the orifice
d) High nozzle symmetry

Experimental results

The processing of the nozzle is based on FINE (Full photolithograph Inkjet Nozzle Engineering) technology which is used in printhead for PIXMA printer and imagePROGRAFF wide format printer. The nozzles are made of photosensitive resin which has capability of producing various nozzle shape and wide range of nozzle dimensions [1] [2]. The examples of commercial printheads are shown on fig.2.

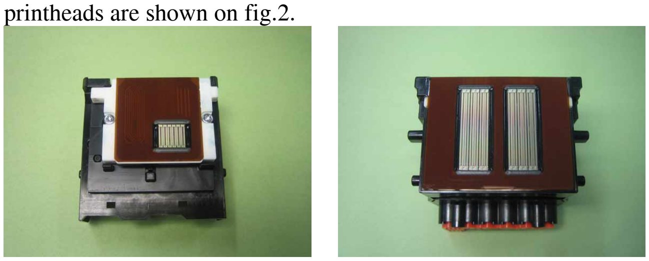

Figure 2. *left) Printhead for PIXMA mini, four colors, 0.2inch print width right) Printhead for imagePROGRAFF, 12 colors, 1 inch print width*

The FINE process starts from the silicon wafer covered with heater, power driver, logic circuits, and so on. Then the first photosensitive resin layer A is coated, exposed and developed to form the shape of the nozzle. The second photosensitive layer B is applied to cover the resin A. This layer becomes the nozzle walls and the nozzle ceiling containing the orifices. The layer B is exposed, developed and the layer A is removed to complete the nozzle.

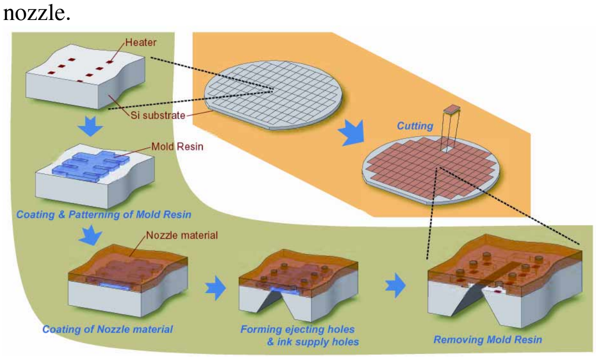

Figure 3. *FINE nozzle manufacturing process*

By carefully controlling the thickness of layer A and B, nozzle dimension of wide range can be realized. In fig.4, the examples of nozzle cross-section are shown. Thickness of the outlet is 50 microns and 10 microns each with a droplet volume of 30 picoliter and 1 picoliter. The processing parameters like concentration of the resin to the coating solution, rotating speed of the coating disc, baking time and temperature are selected to produce very thin layer. Then the layer is exposed to UV light using the stepper for semiconductor manufacturing process. Since the layer is very thin, the light energy to process the orifice can be minimized to produce fine and precise shape. To create the conical tapered outlet, the focus of the optical system is adjusted. The amount of the taper angle varies with the offset distance of the optical focus to the surface of the nozzle. The alignment precision among the orifice, the nozzle and the heater are very high due to the accuracy of exposing equipment.

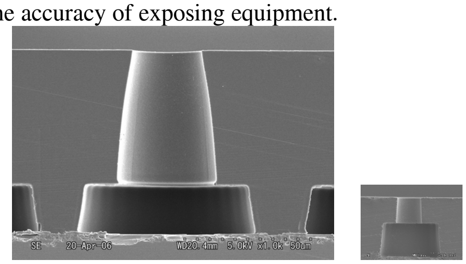

Figure 4: *SEM cross section of 30pl nozzle (left) and 1pl nozzle (right)*

Fig. 5 shows the droplet velocity of 1 picoliter droplet and 2.5 picoliter droplet as the function of the outlet thickness and the taper angle. Very thin nozzle of 3 microns thickness and well tapered nozzle of 15 degrees has achieved. The velocity increases on the thinner outlet and higher taper angle as predicted. Sensitivity to these two dimensions is higher in the case of 1 picoliter nozzle than in 2.5 picoliter nozzle. The reason of this behavior is that the smaller nozzle has the higher flow resistance so the reduction rate of the flow resistance is larger.

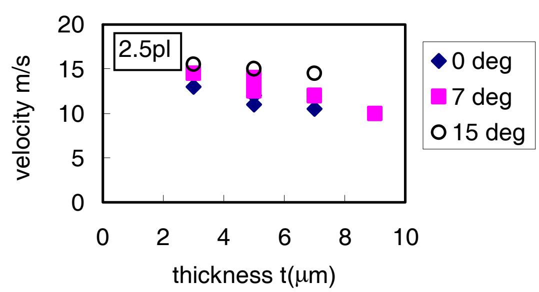

Figure 5a: *Effect of the thin outlet and tapered outlet(2.5pl).*

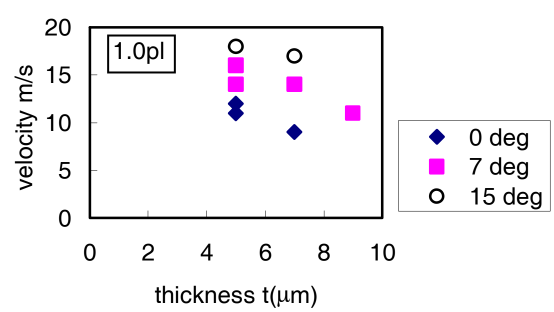

Figure 5b: Effect of the thin outlet and tapered outlet(1.0pl).

The sensitivity to the asymmetry rate was measured by intentionally misaligning the nozzle. Positions of the several chosen nozzles are slightly moved in the photomask. By comparing the ejection direction and the deposition location to those of the neighboring nozzles, the effect of nozzle asymmetry is calculated. The result has fit well to the prediction of the 3D flow simulation. The amount of misdirection is more than twice larger in 3 micron-thick nozzle than in 5 micron-thick nozzle.

Fig.6 shows the SEM cross section of processed nozzles. The drop volume of each nozzle is measured and shown in fig.7. The finest orifice of 2 microns with thickness of 3 microns has produced tiny 0.1 picoliter droplet with 8 m/s velocity. 0.2 picoliter droplet with 12 m/s is achieved from 3micron orifices. The distance from heater to orifice is 22 microns and maximum volume of 10 picoliter droplet can be ejected in this dimension. Namely the droplet volume ranging from 0.1 picoliter to 10 picoliter can be ejected from single printhead.

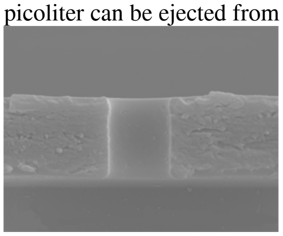

***Figure 6a:** SEM cross section of 0.1pl nozzle, thickness 3mm, diameter 2microns*

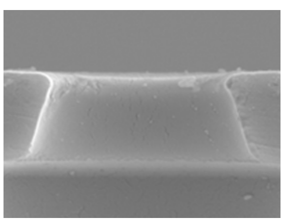

***Figure 6b:** SEM cross section of 0.6pl nozzle, thickness 3mm, diameter 7microns*

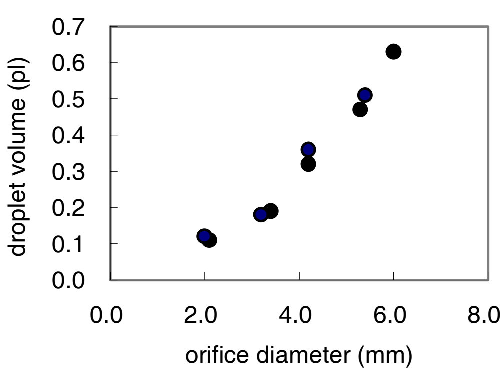

***Figure 7.** Droplet volume from various orifice diameter*

Conclusions

The requirements for stable ejection and precise deposition of the sub-picoliter droplet are clarified. They are;

a) Thinner outlet thickness
b) Conical outlet shape
c) Precise processing of the orifice
d) High nozzle symmetry

Thin outlet of 3 microns, conical outlet of 15 degrees, fine orifice diameter of 2 microns and nozzle with high symmetry is achieved using photolithographic process and photosensitive resin. The stable ejection of 0.1 picoliter is observed.

References

[1] Mineo Kaneko and Hiroto Matsuda, New Bubble Jet Print Head for Photo Quality Printing, Proc. NIP15, pg. 44. (1999)

[2] Mineo Kaneko, Kazuhiro Nakajima and Hiroto Matsuda, High Speed High Image Quality Printing on Plain Paper Using Symmetrically Arranged Color Bubble Jet Print Head, Proc. NIP19, pg. 354. (2003)

Author Biography

Mineo Kaneko received his MS in physics from Waseda University in 1984. Since then he has worked on the research and development of bubblejet p rinthead at Canon Inc.