Development of an Electrostatic Drop-On-Demand inkjet Device for Display Fabrication Process

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Abstract

This paper presents a novel electrostatic drop-on-demand inkjet device featured by a MEMS fabricated pole-type and hole-type nozzle with tube shaped orifice and investigates the feasibility of applying the inkjet device to display fabrication process. The electric voltage signal applied to the ring shaped upper electrode plate, against the hole-shaped ground or pole-shaped ground, referred here pole-type and hole-type nozzle respectively, allows ejection of small droplet to take place: That is, a tiny droplet is taken away from the peak of the mountain shaped liquid meniscus formed at the nozzle orifice. It is verified experimentally that the use of the pole type nozzle allows a stable and sustainable micro-dripping mode of droplet ejection for a wider range of applied voltages and of liquid viscosities. This demonstrates a feasibility of electrostatic drop-on-demand inkjet device as a disruptive alternative to conventional print heads such as thermal bubble or piezoelectric inkjet heads.

1. Introduction

Most of the drop-on-demand print heads available to date are based on pushing out the liquid in a chamber through a nozzle by actuators, such as thermal bubble and piezoelectric actuators. The performance of these print heads depends critically on that of actuators, since the power exerted by the actuators determines the droplet speed and volume, and ultimately the ejection frequency [1]. For the print heads based on pushing, a considerable portion of the actuator power has to be wasted either along the flow path to the orifice or along the flow inlet by a backflow. This waste of actuator power may become more serious as the size of devices is scaled down in order to increase the device density. For a thermal bubble actuator, keeping excessive heat of a device from influencing neighboring devices is also critical, which is in fact a very limiting factor for further scaling down of a thermal bubble print head. Lastly, there are rather serious limitations on the properties of liquid that piezoelectric or thermal bubble print heads are capable of handling due either to viscosity or to chemical composition.

Alternatively, the authors have been proposing and developing an electrostatic drop-on-demand print head [2] that is capable of overcoming the limitations of piezoelectric and thermal bubble print heads described above. The inkjet head consists of a ground electrode which exists in the nozzle and an extractor electrode. Driven by capillary attraction, ink gets through the micro nozzle, and reaches the tip of the nozzle. The intense electric field between the ground and extractor electrodes induces the liquid at the apex of the liquid meniscus to form a tiny droplet. When the force of electric field is stronger than the surface tension on the liquid meniscus, the liquid droplet can be generated.

Although electrostatic jetting (called as electrospray) based on electrohydrodynamics(EHD) has been studied for long [3], it concerned mainly on spraying a uniform size of tiny droplets for coating applications. There has been little in-depth study on the drop-on-demand control of a droplet in micro dripping mode to date. Recently, a pioneering work on this direction was proposed [4], where it showed that a droplet can be separated from the pinnacle covered with a liquid film. The strong electric field concentrated around the pinnacle induces dielectric charge separation. However this approach needs high operating voltages and the externally existing electrode.

Instead of using a pinnacle covered with a thin film of liquid, we take the direct approach to a drop-on-demand control of micro dripping under nozzle based electrostatic ejection as well as to a inkjet device configuration suitable for MEMS fabrication. In this paper we design and fabricate a novel mechanism of electrostatic drop-on-demand inkjet head, and then investigated its jetting performance and the feasibility of the application to display fabrication process.

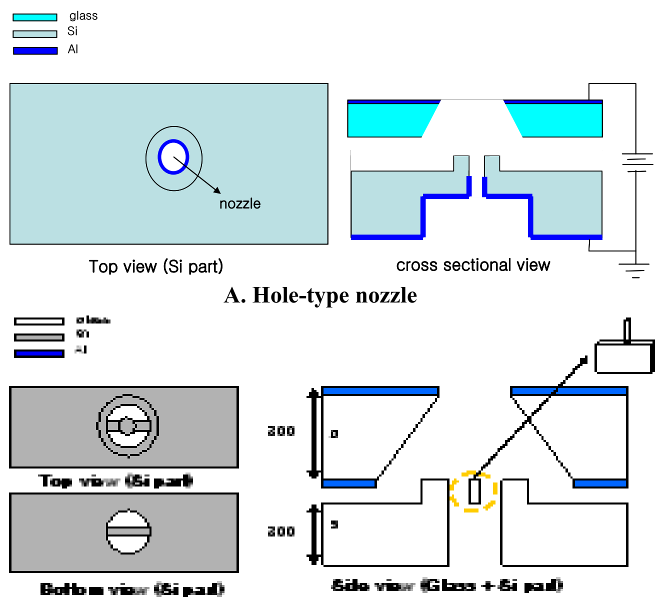
2. Design

Figure 1 represents schematically the structure of the MEMS fabricated inkjet devices featured by hole-type and pole-type ground electrodes. The electric voltage signal applied to a ring shaped upper electrode plate against pole-type or hole-type electrode allows a micro-dripping mode of droplet ejection to take place. That is, only a tiny droplet is taken away from the apex of the concave liquid meniscus formed at the nozzle orifice. Different from the cone-jet mode, a small portion of liquid around the top of the liquid meniscus is separated from the liquid body and pulled away along the electric filed. There is no waste of power along the flow path to the orifice or along the flow inlet by a backflow. Furthermore, there exists no direct connection of droplet volume to device size, providing more freedom for design. The fact that a droplet is simply taken away from the top of the liquid meniscus makes the electrostatic micro droplet ejector capable of handling a much wider range of liquid properties for ejection.

This electrostatic drop-on-demand inkjet device comprises a glass part with control electrode and silicon part with pole-type or hole-type nozzles as shown in figure 1. The pole-type and hole-type ground electrode can give the advantage of stronger electric field than the case of bottom ground electrode. The bottom ground electrode means that there exists the ground electrode on the bottom of the reservoir.

From experiments, the tube-shaped nozzle orifice is designed to form stable convex geometric shape of the meniscus, which can give similar effect to hydrophobic surface treatment [5]. In figure 1, the protruding nozzle is presented. Figure 2 compares the shapes of meniscus for flat and tube shaped nozzles. The flat nozzle is fabricated by only etching the wafer and making a hole. The other is fabricated by making the protruding part on the wafer surface, which can give stable form of the meniscus. As the height of the tube shaped nozzle increases, the electric field along the periphery of the meniscus can be more concentrated. The height may be limited by the fabrication technology.

The pole-type device comprises a glass top-layer part with control electrodes and silicon bottom-layer part with nozzle and pole shape ground electrode. This may give partly better concentration of electric field around the center of orifice and allows a stable and sustainable micro-dripping mode of droplet ejection.



B. Pole-type nozzle

Fig. 1 Illustrations of electrostatic drop-on-demand inkjet device.

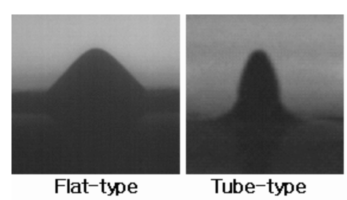


Fig. 2 Comparisons of meniscus shape at the orifices for flat and tube-shaped nozzles

3. Fabrication

Figure 3 shows the fabrication process of electrostatic inkjet device with hole type nozzle. The fabrication process is as following:

(A) Glass part: top electrode layer

a) A glass wafer (pyrex 7740) is used as a substrate. The aluminum (2000 Å) is deposited by sputter on the

Topside. b) DFR is coated by laminator and patterned. The glass wafer drilled by sand blaster.

(B) Silicon part: bottom nozzle layer

a) A double-side silicon wafer (100) is used as a substrate. The silicon oxide (2um) is deposited by LPCVD to use second mask layer. b) A 17 micron thick positive photoresist (AZ9260) is spun (3000 rpm for 30 seconds) on the backside. After making a mask by a photoresist layer, the silicon (250um) is anisotropic etched by ICP RIE. The orifice diameter is about 200um. c) After making a patterned mask by a photoresist layer, a silicon oxide layer is etched by RIE. d) A phtoresist layer is spun (3000 rpm for 30 seconds) on the topside to use first mask layer. Before making nozzle, the silicon (100um) is etched by ICP RIE. e) For making a nozzle and tube-shaped orifice, silicon (50um) is anisotropic etched by ICP RIE. f) For making a hole-shaped ground electrode, the aluminum (1um) is deposited by sputter.

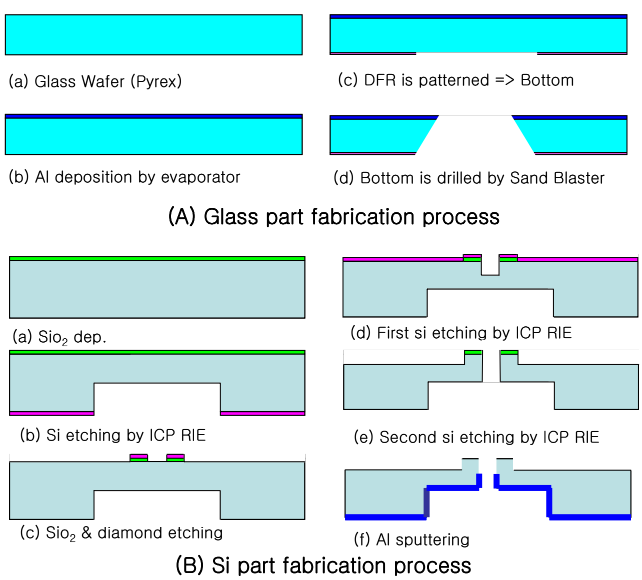


Fig. 3 Fabrication process of electrostatic drop-on-demand inkjet device with hole type nozzle.

The fabrication process of electrostatic inkjet device with pole type nozzle is presented in figure 4.

(A) Glass part: top electrode layer

a) A glass wafer (pyrex 7740) is used as a substrate. The aluminum (2000 Å) is deposited by sputter on the Topside. b) DFR is coated by laminator and patterned. The glass wafer drilled by sand blaster.

(B) Silicon part: bottom nozzle layer

a) A double-side silicon wafer (100) is used as a substrate. A 17 micron thick positive photoresist (AZ9260) is coated by spin coating (3000 rpm for 30 seconds) on the topside. b) After making a mask by a photoresist layer, the silicon (50um) is anisotropic etched by ICP RIE. The orifice diameter is about 150um. c) PR is removed. d) A 17 micron thick positive photoresist (AZ9260) is spun (3000 rpm for 30 seconds) on the backside. e) For making a nozzle, silicon (450um) is anisotropic etched by ICP RIE.

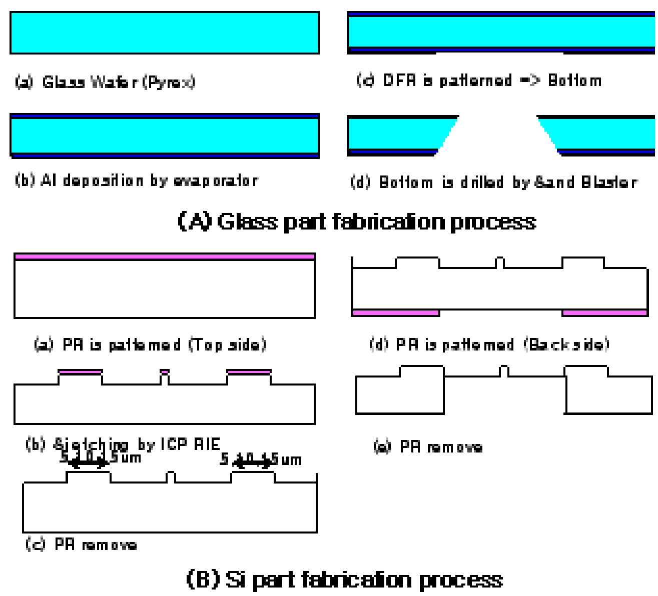


Fig. 4 Fabrication process of electrostatic drop-on-demand inkjet device with pole-type nozzle.

Figure 5 shows the SEM images of the pole type device fabricated based on bulk and surface micromachining on a low resist silicon wafer.

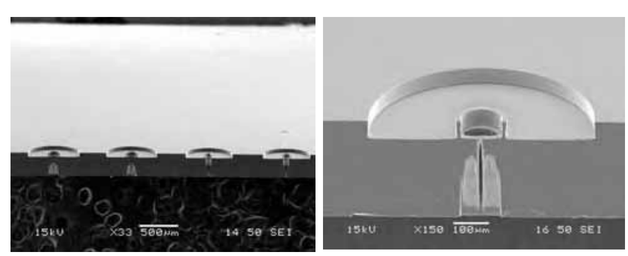


Fig. 5 SEM images of pole type ground electrode by MEMS fabrication.

4. Experiment

Figure 6 shows a schematic of the experimental setup. The Al electrode is connected to a high voltage power supplies and a high speed camera (IDT XS-3) with a micro-zoom lens and a halogen lamp were used to visualize droplet ejection. Liquid was supplied into a nozzle.

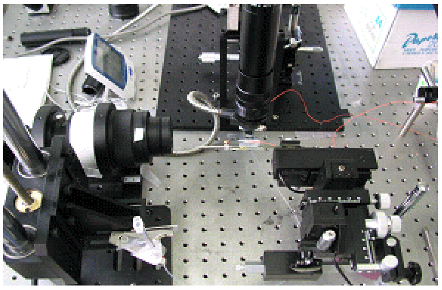


Fig. 6 Illustrations of the experimental setup.

presents a novel electrostatic drop-on-demand inkjet device with a tube-shaped orifice that we are developing.

Figures 7 and 8 show the images of droplet ejection by the fabricated inkjet devices with hole-type nozzle and pole-type nozzle. Droplets can be shown to be taken away from the apex of the concave liquid meniscus formed at the nozzle orifice. Here we used typical ink whose viscosity is 10cp for the hole type nozzle as shown in figure 7. And for the pole type nozzle device, we used acetone whose viscosity is 3cp.

From our previous studies [6, 7], the microdripping mode can appear under identical experimental conditions of applied voltage and flow rate. Also it depends on the liquid properties such as electric conductivity, surface tension, and viscosity. An interesting characteristic of microdripping is that droplet ejection takes place at regular frequencies ranged from a few tens of droplets to several tens of thousands of droplets per second, giving uniform droplet sizes. The droplet diameters ranged from about 100 μm to a few micrometers.

Similarly a stable micro dripping mode or Cone-jet mode of ejection is observed under the voltages ranged from 1.2 and 2.0 kV, as shown in figures 7 and 8. The gap between upper electrode and the nozzle orifice is 1.2 mm. This experimental results show that tube-type orifice with hole-type nozzle or pole-type nozzle can generate stable monodispersed droplets and be applied to the fabrication of display.

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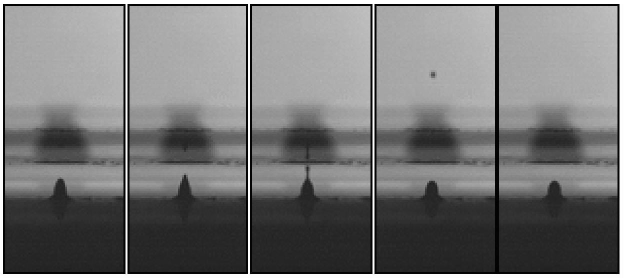

Fig. 7 Jetting images of electrostatic micro droplet ejector with a hole-type nozzle. The liquid is used ink .The viscosity of ink is over 10cp, and the surface tension is about 30.8dyne/cm. The gap between upper electrode and nozzle is about 1.2mm.

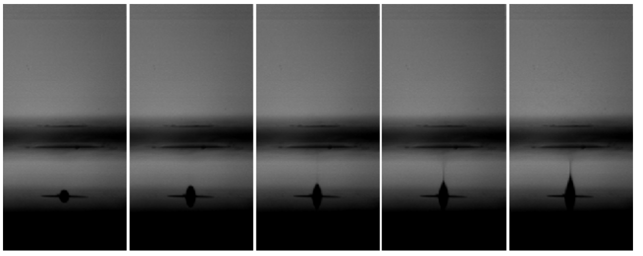

Fig. 8 Jetting images of electrostatic micro droplet ejector with a Pole-type nozzle. The liquid is used Acetone .The viscosity of acetone is over 3.2cp, and the surface tension is about 23dyne/cm. The gap between upper electrode and nozzle is about 1.2mm.

3. CONCLUSIONS

We've suggested a noble concept of the electrostatic drop-on-demand inkjet device featured by a MEMS fabricated pole-type and hole-type nozzle with tube shaped orifice, which can generate and eject the micro liquid droplets. The electric voltage signal applied to the ring shaped upper electrode plate, against the pole-type ground electrode or hole-type ground electrode, allows a micro-dripping ejection of droplet to take place. That is, a tiny droplet is taken away from the peak of the mountain shaped liquid meniscus formed at the nozzle orifice. It is verified experimentally that the use of the electrostatic drop-on-demand inkjet device allows a stable jetting mechanism for a wider range of applied voltages and of liquid viscosities. This demonstrates a feasibility of electrostatic drop-on-demand inkjet device as an alternative to fabrication technology for display.

5. Acknowledgements

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6. References

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