# Development of Micromachined Electrohydrodynamic Inkjet Printing Head

***Kyoung Il Lee[*,**], ByungJik Lim[*], Hyunju Lee[*], Seong Hyun Kim[*], Churl Seung Lee[*], Jin Woo Cho[*], Yongtaek Hong[**]; *Korea Electronics Technology Institute, **Seoul National University; Korea***

## Abstract

*A micromachined electrohydrodynamic inkjet printing head has been fabricated out of glass wafer and stable patterning of uniform fine lines has been realized.*

*We applied a sandblasting process on a glass wafer to fabricate tiny nozzles with a inner diameter of 60 microns and outer diameter of 100 microns. We observed a continuous cone jet mode at a DC bias voltage of 2 kV. Line patterns are printed with black carbon ink and the line width about 25 microns are achieved without any special surface treatment. The thickness of printed line was several hundred nanometers, which is much larger than that from conventional inkjet printing systems. Drop on demand printing up to 3 kHz was demonstrated also by applying pulse signals on a nozzle. Silver particle inks are also printed well and continuous line patterns are fabricated.*

## Introduction

As a flat panel display industry becomes mature, need for low cost fabrication technology get stronger. One of the candidates for reducing the fabrication cost is to substitute traditional photolithography by direct printing. Due to the recent development of inkjet printing technology, there are several applications using piezoelectric inkjet printing process in a mass production of liquid crystal display (LCD) such as color filter or polyimide layer. But the conventional piezoelectric inkjet printing technology has several problems such as nozzle clogging, limited viscosity range of ink, and difficulty for printing of continuous lines.
Electrohydrodynamic (EHD) printing has gathered much attention as a next generation inkjet printing technology after the demonstration of submicron patterning capability [1, 2]. Glass capillaries or metallic tubes were used in most studies [1-4] because the sharp shape of capillaries is required for the strong field concentration at the end of the capillaries.
But the throughput of EHD printing process with a single capillary is not enough for commercialization. Though we can make a multi nozzle printing module by assembling a large number of capillaries, extremely precise alignment during assembly process is required to obtain enough position accuracy for mass production. The cost of capillaries also matters. So an integrated multi nozzle array by batch process is indispensable for the commercialization of EHD printing technology. Some groups have shown silicon based micromachined nozzle for EHD printing since silicon is easy to make a nozzle-shape structure using deep silicon etching process [5]. But the stable jetting could not be obtained due to the electrical conductance of silicon, which reduces the concentration of the electric field at the meniscus. Also, the bias voltage required to eject droplets from the nozzle is higher than several kV. So insulating substrates such as glass wafers are good candidates for the fabrication of nozzles for EHD printing. Unfortunately, the etching process of insulating substrate with a high aspect ratio is not available unlike silicon.
In this paper, we present a nozzle shape glass structure fabricated by sandblasting process.

## Design

The aspect ratio we can achieve for a glass wafer is usually smaller than 5:1. At first, we calculated the field concentration at the end of the nozzle with various structural parameters such as height or diameter using finite element method package, ANSYS. We found that the nozzle with an aspect ratio of 5:1 requires 20 % larger electric field than that of extremely long nozzle, which is acceptable for printing experiment.
The shape of our device is illustrated in Figure 1. The condition of nozzle can be monitored by the side during printing process. The inner diameter of the nozzle is 50 microns while the outer is 100 microns. The height of the nozzle is about 200 microns. The size of each die is 3 mm x 3 mm.

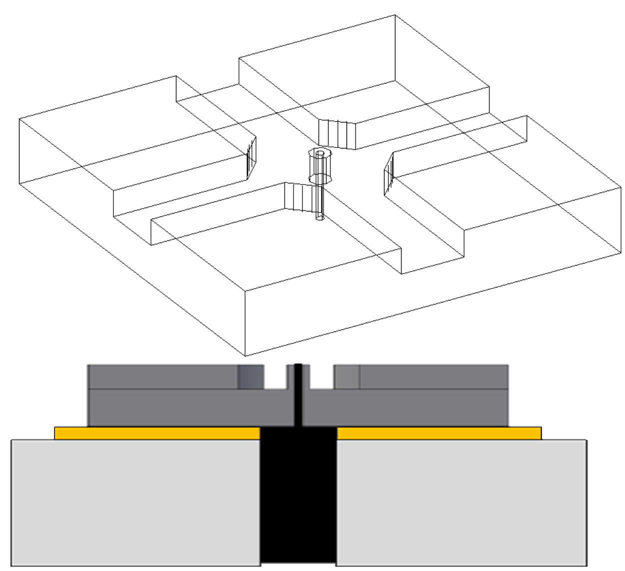

***Figure 1**. Schematic of glass nozzle die(upper) and cross section of module after assembly(lower) The dark grey color corresponds to glass nozzle die, black to ink, and bright grey to tubing*

## Fabrication

We use a 500 micron thick boro-33 glass wafer as a starting material. See Figure 2 for the fabrication process of glass nozzle die. At first, the tiny holes with a diameter of 150 microns are made on the back side by sandblasting. The masking material for

 

the selective etching during sandblasting process is a dry photo resist (DFR) with a thickness of 50 microns and patterned by conventional photolithography. Then, 50 micron diameter holes aligned with the holes on the back side are fabricated on the front side with the same process until the wafer is penetrated. DFR is patterned on the front side again to define the outer shape of nozzle. The DFRs are removed after sandblasting process and diced into individual die.
The dies are cleaned since there are many small particles after sandblasting and dicing process. The wetting of ink on the side wall of nozzle results in unstable meniscus formation. So Teflon layer is spray-coated on the front side with Teflon AF 1601 (Dupont) solution to make the side wall of the nozzles hydrophobic. The contact angle becomes 110° after Teflon coating while it was 30° on a bare glass wafer for deionized water.
After the Teflon coating process, the dies are attached by epoxy on a plastic adaptor having a hole with a diameter of 0.1 mm, which is connected to an electrode.

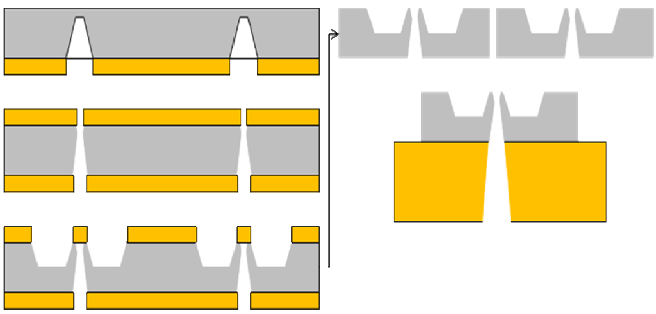

***Figure 2**. Fabrication process for glass nozzle*

Figue 3 shows the nozzle end and the printing module after assembly. The rough surface is observed right after the sandblasting process and chemical etching with Hydrofluoric acid is followed to reduce the roughness before Teflon coating process. The innder diameter becomes 62 microns after sandblasting. The cylindrical rod with metallic color has a ink path inside and are connected to the high voltage power supply and to ink reservoir. We can observe a slight overhang at the edge of nozzle, which helps the definition of meniscus.

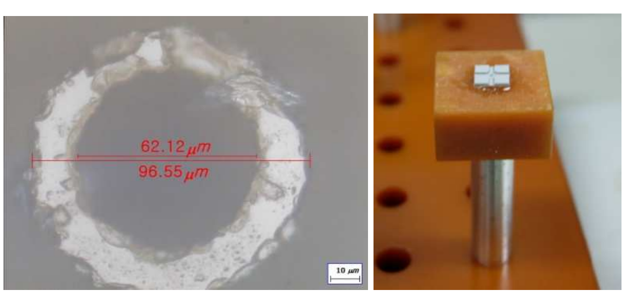


***Figure 3**.End of glass nozzle (left) and printing module after assembly (right)*


***Figure 4**. Oblique view of glass nozzle (left) and side view of the nozzle (right))*

## Printing test

We tested our printing module with a system illustrated in Figure 5. The metal electrode is connected to an high voltage amplifier (Trek, 10/40A) controlled by a function generator (NF 100, NF). We can control the meniscus by controlling air pressure in the ink reservoir with a pressure controller (PPM, Unijet). We tested our nozzle in a constant pressure mode instead of constant flow rate mode because the constant pressure mode is more appropriate for drop on demand printing process. In a constant flow rate mode, unwanted drop dripping could occur after a long time of rest.
The jetting behavior was monitored by high speed video camera(, Phantom v12.1, Vision Research) with a optical fiber illumination or LED stroboscope type drop watcher equipped in a lab-scale inkjet printing system(UJ-200, Unijet). The substrates are placed on a vacuum chuck grounded and PC-controlled motorized XY stage equipped in the inkjet printer are used for a line printing.

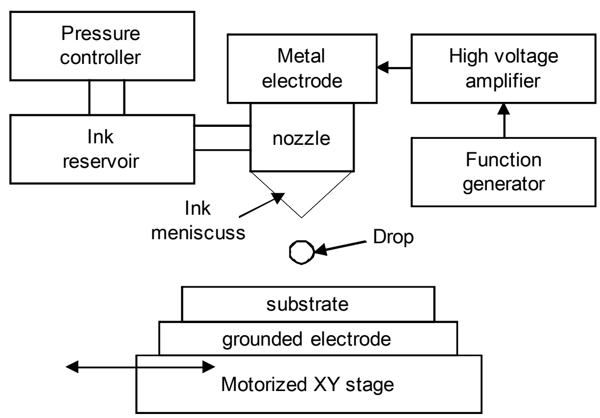


***Figure 5**.Printing equipment*

We tested several inks such as dye inks for OA, carbon black ink, Ag inks. One of the best appropriate inks for EHD printing is a carbon black ink. We could achieve a stable continuous cone jet mode (Fig. 6) to draw continuous lines on both silicon wafer and glass wafers. We can observe a stable cone jet mode at a DC bias voltage from 1.4 kV to 2.0 kV. The printing on a 500 micron thick borosilicate glass wafer requires a DC bias voltage more than 2 kV. The width of the printed line varies from 20 microns to 100 microns depending on the stage speed and the bias voltage. We could observe a line pattern with a width of 20 microns at the stage speed of 500 mm/s. This is obtained without any special surface modification such as hydrophobic treatment on the substrate unlike the conventional inkjet printing process.

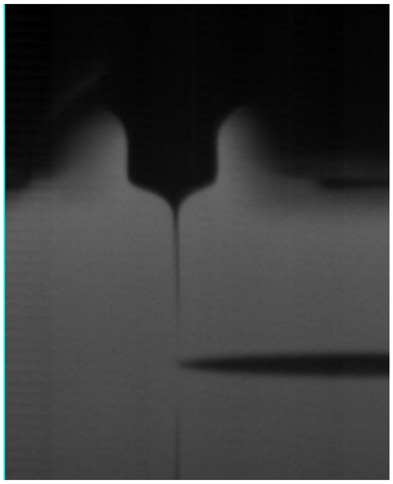

***Figure 6****.Jetting from the meniscus in cone jet mode.*

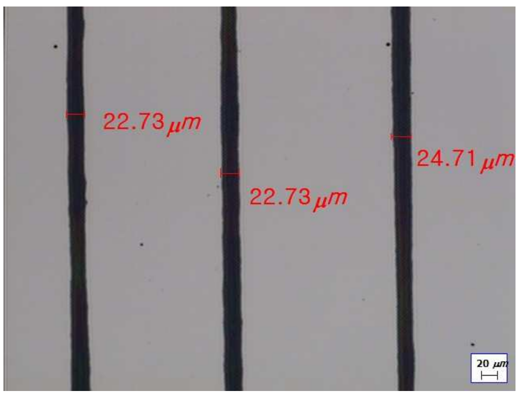


***Figure 7****.Lines printed by cone jet mode printing ( stage speed : 500 mm/s, bias voltage : 1.7 kV)*

The line width can be controlled by changing the bias voltage as shown in Figure 7, though the relation is not linear.

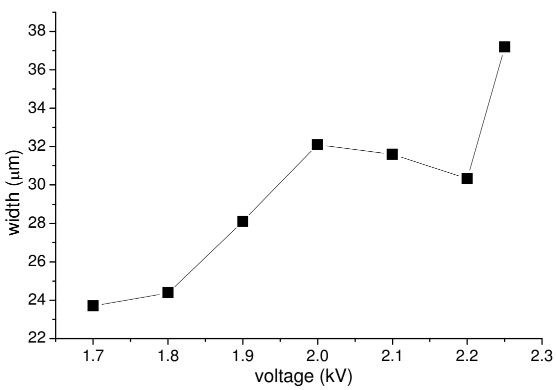


***Figure 8****.Printed line width versus applied DC voltage*

So we can achieve a smaller pattern than the diameter of the nozzle unlike the conventional inkjet printing head, which means nozzle clogging problem can be reduced seriously, especially in a mass production.

Also, the thickness of the line pattern for a 25 micron width is more than 400 nm as shown in Figure 9. Usually we could get a thickness below 100 nm for the same ink with a piezoelectric inkjet printer with similar line width. So much thicker pattern can be printed by EHD printing, which is important to the application of electrode printing. At the low stage speed, we can get a 4.8 micron thick line patterns with a width of 130 microns, which is comparable to a screen printing process.

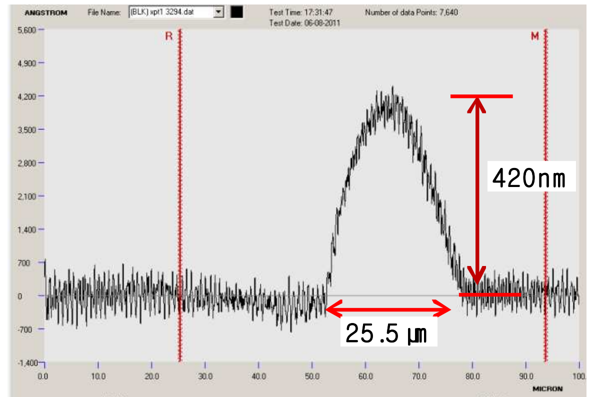


***Figure 9****. IS&T logo (note the use of bold and italics)*

Also, dot array patterns were printed by applying pulsed signal with a DC offset bias. The jetting frequency can be increased up to 10 kHz and the diameter of the printed circular patterns was about 45 microns with a jetting frequency of 3 kHz at the stage speed of 200 mm/s. There is a tendency of increasing drop volume according to the increasing duty.

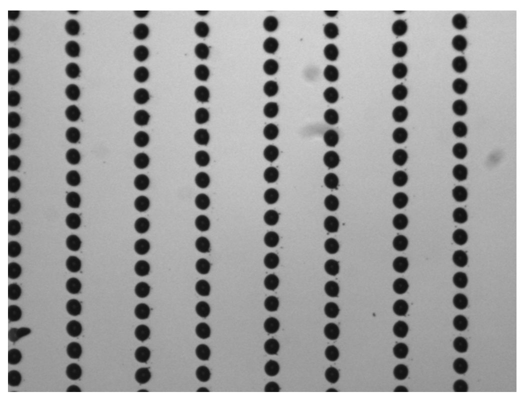

***Figure 10****.drop printing by pulse signal*

We tested the stability of our printing module by printing whole 6" wafer with a line space of 200 microns but there was no noticeable change in the printed patterns during the whole printing process. Also there is no degradation at the nozzle after the wafer scale printing. It is clear in the sense that there is no mechanical part inside the nozzle and glass is very inert to most organic solvents used for ink formulation. For these nozzles consist of only glass, we can disassemble the module and clean them when a nozzle clogging problem happens. So the maintenance cost can be seriously reduced in mass production.

We have tested several silver particle inks for electrode patterning applications and get a continuous cone jet mode with some inks from various companies. Figure 11 shows the line printing results on a silicon wafer with one of the printable silver particle inks(NPS-J, Harima). We obtain similar results to that with a carbon black ink.

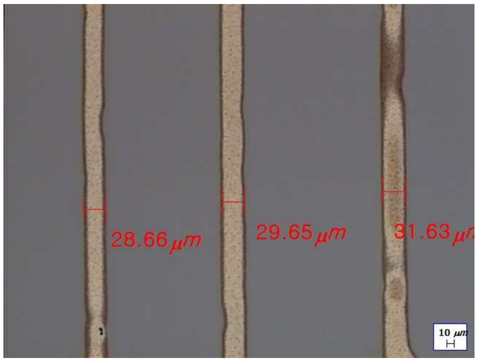


***Figure 11***. *IS&T logo (note the use of bold and italics)*

## Conclusions and future work

In summary, we applied a sandblasting process on a glass wafer to fabricate EHD printing nozzles. The nozzle shows good EHD printing capability with a lot advantage such as fine line width, large nozzle diameter, easy printing of continuous line, and large film thickness comparing with the conventional piezoelectric inkjet printing technology. The fabrication method used in this paper can be directly applied to the batch fabrication of multi nozzle EHD printing module, which enables the commercialization of EHD printing technology.

## References

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## Author Biography

*K. I. Lee received the B.Sc. and M.Sc. degrees in physics from Seoul National University(SNU), Korea, in 1997. He then joined Korea Electronics Technology Institute, Korea. He is currently a managerial researcher in Energy nano materials research center and is a doctoral student in SNU. His focus is a MEMS-based nanotechnology such as inkjet printing with nano-material for an environmentally friendly fabrication process.*