Development of 16 Nozzle Electrohydrodynamic Inkjet Printing Head

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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 electronics 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.

EHD printing technology gathered much attention for higher resolution comparing to traditional piezoelectric inkjet technology and various materials have been fabricated by EHD printing technology [1,2]. High speed drop-on-demand (DOD) printing up to 1 kHz was also demonstrated [3]. Glass capillaries or metallic tubes were used in most studies [1-5] 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. So, multi nozzle printing modules composed of capillaries were reported [6] but it's not practical to assemble large number of capillaries with high position accuracy to make multi nozzle arrays required for commercial applications. 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 [7]. 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 a insulating substrate like glass wafer is a good candidate 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.

We reported a single nozzle printing head with batch processed glass nozzle and it showed a good printing performance on various substrates due to the insulating property of glass [8]. In this paper, the batch fabrication and printing results of EHD inkjet printing head with 16 nozzles are shown

Design

Principle of EHD printing is shown in Fig. 1. Inks can be ejected by large electric field. To avoid electrical breakdown, we need a high aspect ratio nozzle structure to make a localized large field only at the meniscus.

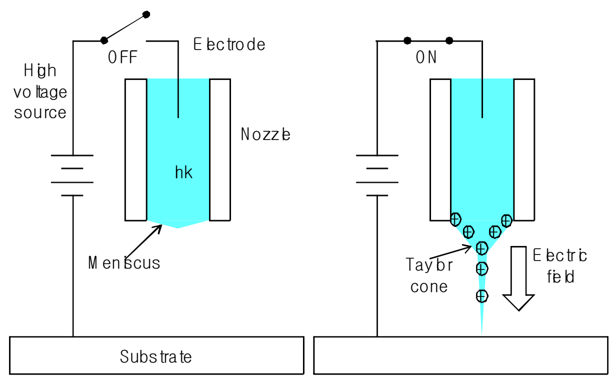

***Figure 1**. Principle of EHD printing*

In the previous study, we fabricated silicon nozzles with a high aspect ratio of 8:1 by dry etching process as shown in Fig. 2 but the printing was not stable. Electrical breakdown happened when the bias voltage increases to apply larger electric field to get a stable jetting.

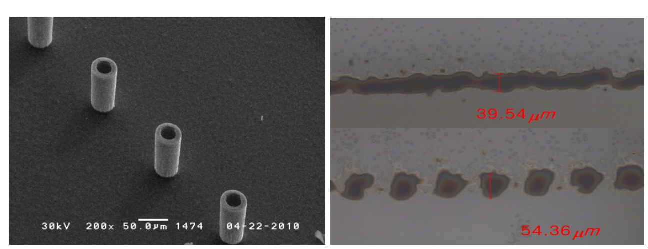

***Figure 2**. Silicon nozzle array and its printing results.*

So insulating material is required for EHD nozzle fabrication. Unfortunately, the aspect ratio we can achieve for a glass wafer is not so high as for silicon. Several etching process were tested. Wet etching was tested but the angle of the etched wall is too low. Dry etching process with a metal mask shows a good etching profile but the process time is too long unlike Bosch process for silicon. Sandblasting shows a good etching profile with a reasonable process time. The aspect ratio we can achieve for a glass wafer is about 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 FEM (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 inner diameter of the nozzle is 60 microns while the outer is 100 microns. The height of the nozzle is about 150 microns. In a multi nozzle array, the field also depends on the distance between nozzles. We also found that the field is proportional to the nozzle pitch below 1 mm and then saturates. So we choose 1 mm as a nozzle pitch in our 16 nozzle inkjet printing head to get both moderate nozzle density and low crosstalk.

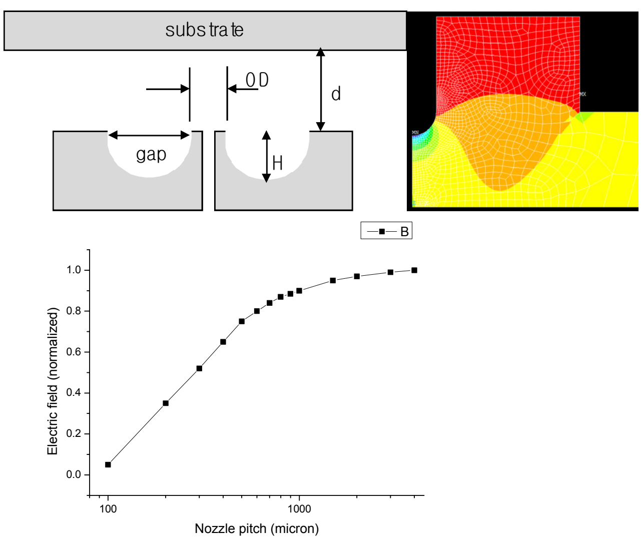

***Figure 3**. Design parameters and FEM result*

The basic concept for multi nozzle EHD inkjet printing head is shown in figure 4. There is an electrode inside each nozzle. This works only for an ink with a very low electrical conductivity since the leakage current between nozzles happens during operation. In this paper, we show only the simultaneous jetting characteristics of nozzle array without individual signal electrode for each nozzle.

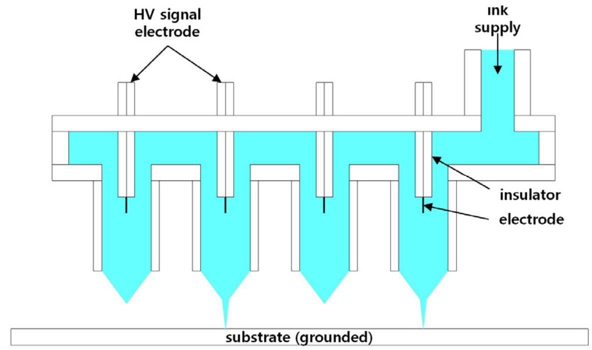

***Figure 4**.Concept of multi nozzle inkjet head*

Fabrication

We use a 600 micron thick borosilicate-33 glass wafer as a starting material. See Figure 5 for the fabrication process of glass nozzle die. At first, the tiny holes with a diameter of 250 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, 60 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 bonding of the nozzle die, a plastic (PEEK) adaptor, and a metal tube to make a printing head, the tube is connected to an ink reservoir and is wired to a high voltage source.

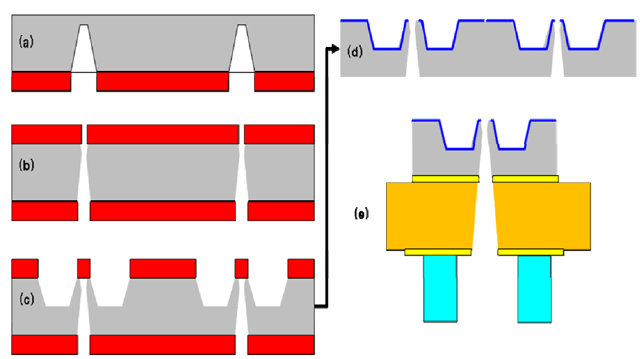

***Figure 5**. Fabrication process for glass nozzle*

Figure 6 shows the fabrication results. 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 uniformity of outer diameter is very important for multi nozzle array since it affect the printed pattern uniformity. The variation of the outer diameter from the above process was about 2 microns and should be reduced to achieve a better uniformity.

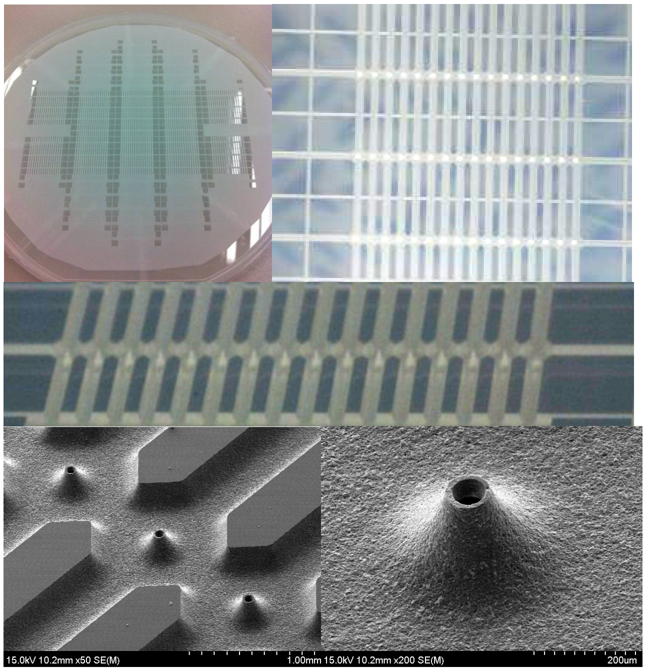

Figure 6. Fabrication results: wafers after batch fabrication (top left), nozzle plates (top right), individual nozzle plate (middle), SEM picture of nozzle(bottom left, and oblique view of the nozzle (bottom right)

Figure 7 shows the nozzle end and the printing module after assembly. We tested a common mode operation which eject at every nozzle simultaneously. So there is no individual electrode for each nozzle.

Figure 7*.Printing head assembly*

Printing test

We tested our printing module with a system illustrated in Figure 8. The metal electrode is connected to a 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 electrically and PC-controlled motorized XY stage equipped in the inkjet printer are used for a line printing.

We tested several inks such as dye inks for office application, carbon black ink for black matrix in LCDs, Ag particle inks. One of the best appropriate inks for EHD printing is a carbon black ink. A stable continuous jetting at DC bias voltage with a commercial carbon black ink was observed at each nozzle (Fig. 9), which is very important for printing quality.

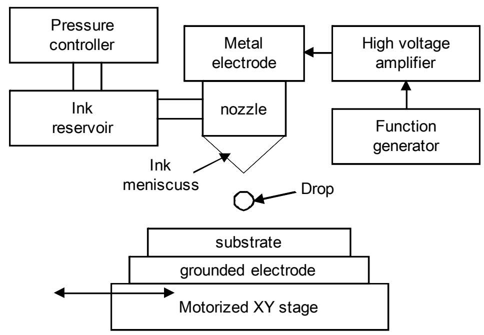

Figure 8*.Printing equipment.*

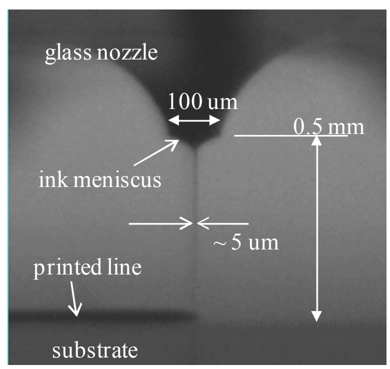

Figure 9*.Jetting from the meniscus in cone jet mode.*

Continuous lines with a width of 22 microns on a silicon wafer were printed simultaneously with a DC bias voltage of 1.9 kV and with a stage speed of 500 mm/s while the gap between the nozzle and the substrate is 150 microns (Fig. 10). With a single nozzle head, we got a minimum line width at 1.6 ~ 1.7 kV. So the bias voltage required to apply the same electric field at the meniscus increases around 10 %, which is expected from the FEM analysis. This is obtained without any special surface modification such as hydrophobic treatment on the substrate unlike the conventional inkjet printing process.

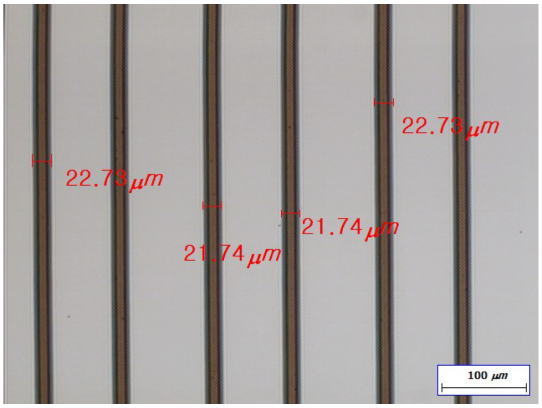

Figure 10. *Carbon black lines printed by cone jet mode printing at the stage speed of 500 mm/s and the bias voltage of 1.9 kV*

Since the speed of the process is very high, this process is appropriate for large area applications. One of them is a conducting grid on dielectric films which is used for flat panel display and electromagnetic shield. Fig. 11 show a conducting grid pattern on a 6" diameter PET film by EHD printing.

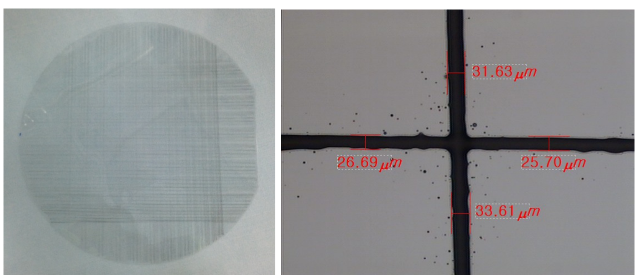

Figure 11*.Grid pattern on a PET film*

To check the quality of printed patterns, we measure the electrical resistivity of the Ag line patterns. We use a Ag nano particle ink (Harima, NPS-JL, Japan) and apply a DC voltage to print a straight line patterns. The line width is about 40 microns and the thickness is 35 nm. For a 10 cm long line pattern, the resistance is 5.2 kohm. So the resistivity is 7.8 x 10-6 ohm cm which is comparable to the ink specification. So we can conclude that the EHD printing process does not affect much of the ink chemistry and can be used for an electrode printing process.

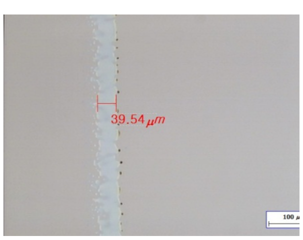

Figure 13*. Ag line for the measurement of electrical resistivity*

Drop on demand printing is tested with the same ink up to 3 kHz but the uniformity is not good at this stage. This will be enhanced after the control of individual nozzle signal.

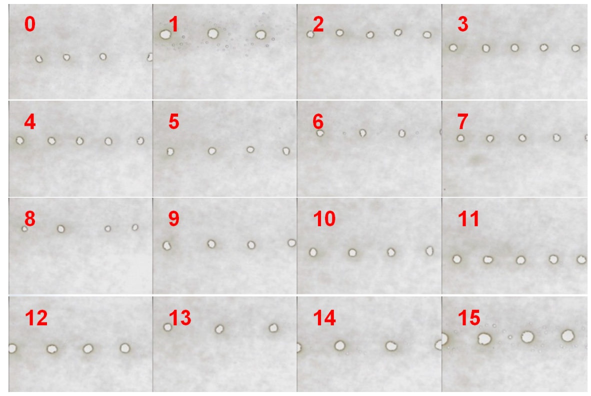

Figure 12*. Pulsed jetting with pulse at 2 kHz*

Beside its high resolution and high speed capability, high viscosity inks can be printed. We use a silver paste (ANP, Silverjet nano paste DGP, Korea) for a gravure offset process and get a pulsating mode instead of stable cone jet mode. Though the jet stream is not continuous, we can get a straight line by decreasing the stage speed. The line width is about 25 microns at the stage speed of 4 mm/s while 6 microns line width shows at 40 mm/s. The thickness is more than 500 nm for a 27 micron width line, which is very difficult to achieve with a conventional piezoelectric inkjet printing process. But the jetting is not stable so the chemical modification of the paste would be helpful.

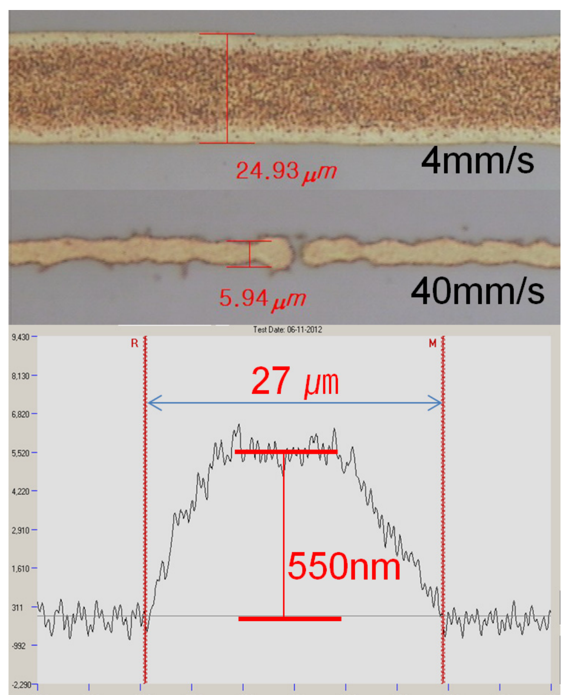

Figure 14*. Pulsed jetting with pulse*

Conclusions and future work

In summary, we applied a micromachining process on a glass wafer to fabricate high aspect ratio nozzle array for EHD printing modules. The module shows good printing capability with a lot of advantages 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. We are developing individual nozzle control and smaller nozzle diameter below 30 microns to achieve narrower lines.

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Author Biography

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