Development of Novel Bend-mode Piezo Inkjet Print Head Utilizing MEMS Technology for Printed Electronics Applications

Yasuo Nishi(1), Shigekazu Sakai(1) , Kusunoki Higashino (2),Yuichi Machida(1) , Koujirou Yoshida(1) ; (1)Konica Minolta IJ Technologies, Inc., Hino-shi,Tokyo,Japan (2) Konica Minolta Technology Center, Inc.,Takatuki-shi,Oosaka,Japan

Abstract

We are trying to develop a new inkjet printing head with the use of MEMS technology for the Printed Electronics applications. The newly developed print head consists of three layers; a nozzle plate, an intermediate plate, and an actuator. The actuator has an unimorph structure with piezo ceramic element. We investigated the effects of a nozzle-hole shape, structures of a pressure chamber and an ink inlet, and finally achieved to drive the actuator to displace small volume of ink with higher frequency by optimizing them.

We also investigated the effects of the nozzle-hole shape and ink repellency of the nozzle plate to minimize the angle deviation of jetted droplets.

1. Introduction

"Printed Electronics (PE) technology" has been receiving plenty of attention recently. It is a technology that has been aimed at manufacturing large area devices such as organic semi-conductor (OSC), organic light emitting diode (OLED), and organic photo-voltaic (OPV), with printing technologies. Among them, the ink jet technology has advantages in low energy consumption, saving resources, and so on. We are trying to develop a new inkjet printing head that is suitable for the PE applications. We adopted the so-called MEMS technology and finally succeeded to develop a new inkjet print head. It can eject small volume droplets precisely and stably with higher frequency and smaller angle deviation, which are essential for the PE applications.

The newly developed print head consists of three layers; a nozzle plate, an intermediate plate, and an actuator. The actuator has an unimorph structure with bulk PZT ceramics. We investigated the effects of a nozzle-hole shape, structures of a pressure chamber and an ink inlet, and finally achieved to drive the actuator to displace small volume of ink with higher frequency by optimizing them. We adopted independent control of the driving voltage for each actuator and succeeded to minimize fluctuation of the droplets' volume. We also investigated the effects of the nozzle-hole shape and ink repellency of the nozzle plate to minimize the angle deviation of jetted droplets. We optimized materials for the print head durable to strong solvents that can solve less-soluble functional materials used for PE applications. We also optimized the structure of the ink channel to jet the less viscous (e.g. 1 - 3 mPa*sec) ink stably by simulating jetting performance.

Combining those results, we finally developed a novel bend-mode inkjet print head that can jet ink droplets in small volume with higher frequency and smaller angle deviation.

2. Structure of the MEMS head

2.1 Product specifications

Table1 shows specifications of the KM128SNG-MB-DPN head. Fig.1 shows the appearance of the KM128SNG-MB-DPN head.

Table 1 Specification of KM128SNG-MB-DPN

Jetting Method	On-demand piezoelectric
Number of nozzles	128(in one row)
Droplet size	1.0pl
Fluid viscosity range	1～5mPa・s
Nozzle Spacing	300μm
Print width	38.1mm
Dimension	67mmW*40mmD*70.02mmH
Maximum frequency	15kHz
Driving Method	DPN (Drive Per Nozzle)
Maximum Voltage	40V

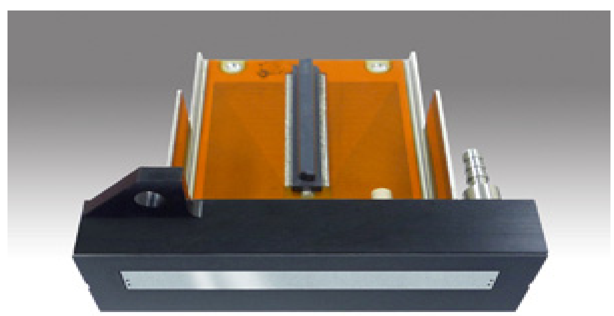


Fig.1 Picture of KM128SNG-MB-DPN

2.2 Structure of the print head

Fig.2 is also a cross-sectional view of an individual MEMS head chip provided with a nozzle.Fig.3 is a cross-sectional view of the MEMS head chip and the ink supply port.

The MEMS head chip having a total thickness of approximately 500μm consists of three plates; a nozzle plate, an intermediate plate, and an actuator. The nozzle plate and the actuator are constructed such that the SOI substrate has been polished by means of chemical mechanical polishing (CMP) to provide a desired thickness and then accurately processed by the deep reactive ion etching (DRIE) process. The intermediate plate is created such that a glass substrate has been processed by the blast process. Those three plates were accurately bonded together, bulk PZT ceramics were then bonded to the silicone actuator, and driver wires were connected; thus, the MEMS head chip has been configured.

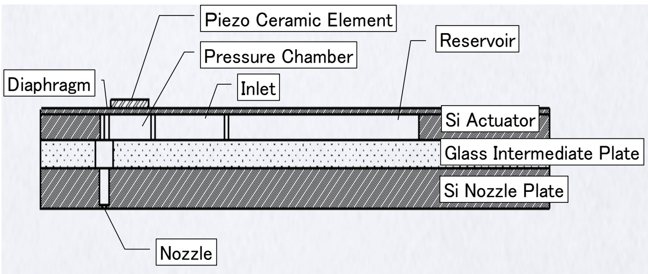


Fig.2 Cross section of an individual MEMS head

Ink is introduced from a supply-side ink connector (supply port), passes through an ink channel provided with a filter, and then supplied to the MEMS head chip.

The ink is supplied from the common ink chamber (reservoir), to an individual pressure chamber through an inlet, and finally to a nozzle. An actuator composed of an approximately 50μm PZT ceramics is disposed on top of the pressure chamber. In this configuration, the application of a voltage in the direction of thickness contracts and deforms the PZT, which causes the volume of an individual pressure chamber to change via the actuator and creates a pressure. Thus, ink is ejected through the nozzle.

Furthermore, air in the MEMS head chip is discharged through the discharge-side ink channel port (discharge port 2). The supply-side ink channel is also provided with an air discharge port (discharge port 1), which facilitates the discharging of air upstream of the filter. Moreover, since parts for the ink channel use chemical-resistant materials and adhesives, they can cope with a variety of solvents as required in industrial applications.

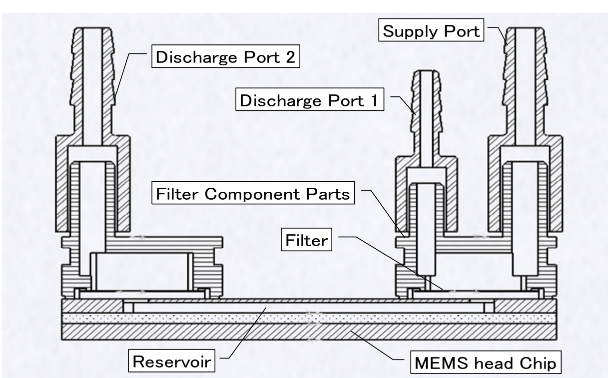


Fig.3 Cross section of MEMS head chip & Ink supply

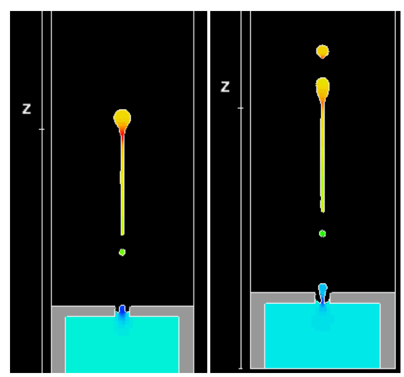
3. Description of main technologies applied to the MEMS head

The newly developed MEMS head has incorporated various technologies so as to stably eject 1-pl small ink droplets through all of the 128 nozzles and accurately place the droplets even when the ink has low viscosity of 1 - 3 mPa.
Next, we will describe main technologies we have studied.

3.1 Design of the ink channel

To eject a small droplet, it is necessary to move the actuator quickly with a small amount of displacement. This means that it is important to shorten the natural oscillation period of the print head. To do so, it is desired that the area of the actuator be as small as possible.

We chose a circular actuator which is advantageous in terms of drive efficiency if the area is the same. We then designed the ink channel for 1-pl ink droplet based on the experiment results of existing print heads and by utilizing the PSPICE equivalent circuit analysis and the ANSYS structural analysis. For design of the ink channel, shapes of the nozzle, pressure chamber, diaphragm, PZT, inlet, and the common ink channel are important factors. For example, depending on the shapes of the nozzle, meniscus' behaviors differ in the droplet ejection process. When droplet ejection is in a stable condition, no satellite droplet is generated as shown in Fig.4a. On the other hand, when droplet ejection is unstable, a satellite droplet occurs as shown in Fig.4b. We studied various characteristics based on such analysis and optimally designed the nozzle shape.



a)Satellite-free condition b)With satellite condition

Fig.4 Jetting condition

3.2 Structure cross talk analysis

To stably eject ink through all of the nozzles in various driving patterns with a different number of ejection nozzles, the print head structure cross talk control is important. We used the ANSYS structural analysis to analyze the print head structure cross talk and optimally designed the print head.

Fig.5 shows the structure cross talk simulation model of the print head chip consisting of the nozzle plate, intermediate plate, and the actuator.

Using the above model, we changed the thickness of the actuator diaphragm, intermediate plate and the nozzle plate within the design range, and calculated the modulus of volume change of each pressure chamber due to structure cross talk at the time of full driving and at the time of one-eighth driving. We then analyzed the relations between the thickness of each plate and the volume change. For the structure cross talk design, it is necessary to keep volume change of each pressure chamber as small as possible.

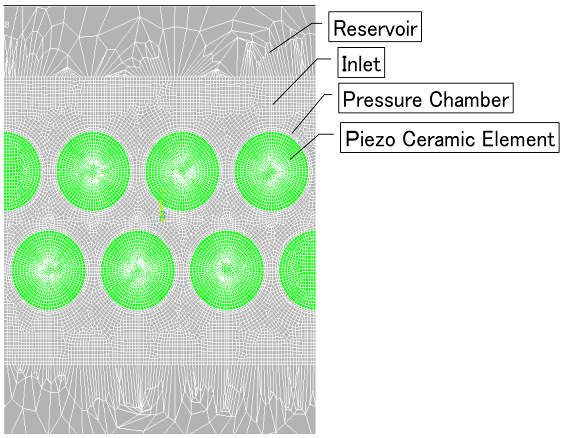


Fig.5 Structure cross talk simulation model

The structure cross talk simulation results are shown in Table 2.The results indicate that structure cross talk can be suppressed when the diaphragm of the actuator is thin and the intermediate plate and the nozzle plate are thick. We studied various characteristics and incorporated them in the design.

Table2 Structure cross talk simulation

Dimension	A	B	C	D	E
Diaphrum thickness(μm)	15	15	15	30	30
Intermediate plate thickness(μm)	200	150	150	150	200
Nozzle plate thickness(μm)	310	310	206	206	310
Modulus of volume change(%)	0.4	0.6	0.7	1.9	1.6

3.3 Highly-accurate silicone nozzle plate

To eject 1pl small droplets through all of the channels without making drop placement errors while minimizing the deviation of droplet volumes, the nozzle plate must be processed precisely.

Specifically, to minimize the deviation of drop placement errors, the water-repellent film must be processed precisely. Fig.6 is a graph showing the results of experiments in which the water-repellent film processing accuracy and its effects on the drop placement error were studied. In the graph, penetration of the water-repellent film into the inner surfaces of nozzles has been studied by using nozzles where drop placement errors occur and nozzles where drop placement errors do not occur, and correlations between the amount of fluorine measured by the auger electron spectroscopy (AES) and the drop placement error were analyzed.

The results reveal that minimizing the penetration of the water-repellent film into the inner surface of a nozzle can prevent an ink drop placement error.

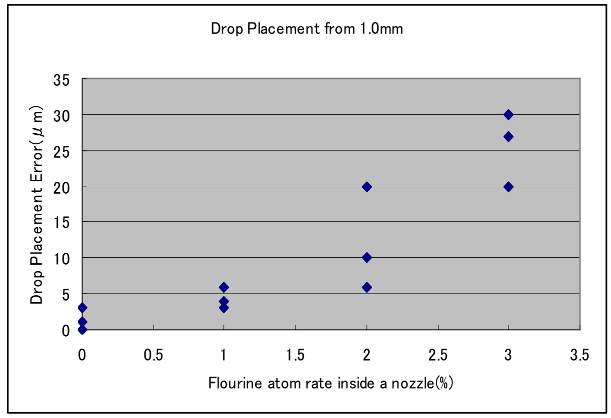


Fig.6 Drop Placement Error vs Non wet layer Processing accuracy

4. Ejection characteristics

Ejection characteristics of the optimally designed print head will be described below.

4.1 Ink drop ejecting condition and drop volume

Fig.7 shows sequential stroboscopic photographs showing the ink drop ejecting condition when chlorobenzene (0.95 mPa.s, 33.8 mN/m), which is low-viscosity solvent ink, was driven with the rectangular wave at 15 khz.

The drawing verifies that 1-pl small droplets have been ejected without creating satellites.(Drop Velocity is 6m/sec)

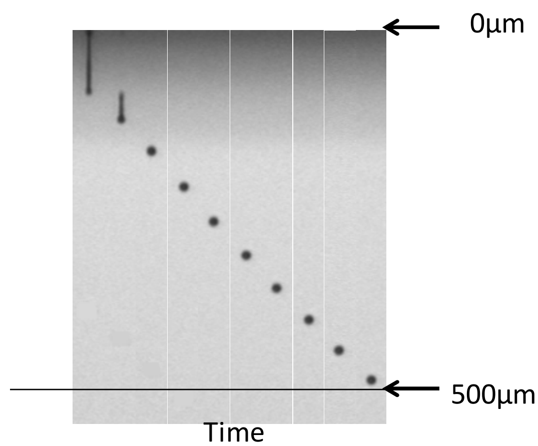


Fig.7 Transition of filament shape at satellite free

An average ink drop volume was calculated by using ink (3mPa*sec) which is not affected by drying, collecting ink drops discharged for a certain period of time, and measuring the weight of the ink drops. Fig.8 shows the correlation between the ink drop speed and the average ink drop volume when ink was ejected from all of the nozzles driven at 15 khz. The results indicate that the obtained average ink dropl volume is the desired 1-pl, and the correlation between the ink drop speed and the ink drop volume is linear.

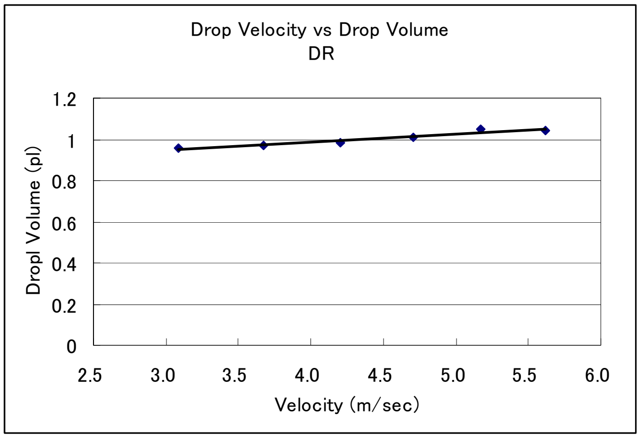


Fig.8 Drop Velocity vs Drop Volume

4.2 Ink drop ejecting angle

Fig.9 shows the deviation of ink drop ejecting angles measured when solvent analog ink (3 mPa/s, 28.6 mN/m) was ejected through all of the nozzles driven at 15 khz. The drawing indicates that 1-pl small droplets were ejected through 128 nozzles with the angle deviation of one degree or less.

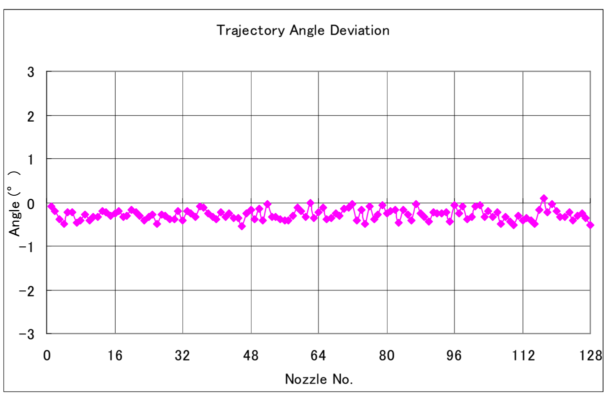


Fig.9 Trajectory Angle Deviation

5. Conclusion

We have established an ink channel design technology, highly-accurate silicone nozzle plate technology, and a highly-accurate MEMS chip assembling technology, and successfully developed the highly-accurate 1-pl MEMS head that can be applied to printed electronics. The newly developed print head can accurately eject small droplets through all of the nozzles without creating a satellite even when the liquid has low-viscosity (e.g. 1 - 3 mPa*sec) that is required for functional materials used for organic semi-conductors and organic light emitting diodes (OLEDs). By utilizing the print head for printable electronics, achievement of high image quality electronic paper, organic semi-conductors in smart phone applications, OLD processes, semi-conductor COC re-wiring processes, the next-generation semi-conductor process in combination with nano-imprint, and even bio-printing can be expected. In the future, we will strive to develop elemental technologies necessary for achieving high-density multi-nozzles and smaller droplets which are expected for the high-definition IJ for the purpose of the commercialization of new products.

References

[1] Young-Seuck Yoo,Changsung Sean Kim,Yoon Sok Park,Won-Chul Sim,Changsung Park,Jaewoo Joung,Jin-Goo Park,and Yongsoo Oh:Numerical and Experimental Evaluation of Picoliter Inkjet Head for Micropatterning of Printed Electronics,JJAP49(2010)

[2] Ikuo Yoneda, Shinji Mikami, Takumi Ota, Takeshi Koshiba, Masamitsu Ito, Koji Hashimoto, Tetsuro Nakasugi, andTatsuhiko Higashiki：Leading-edge device applications of nanoimprint lithography ,SPIE(2008)

[3] Masato Nakamura :NAKAMURA/BIOPRINTING /PROJECT INVESTIGATION DIGEST(2008)

Author Biography

Yasuo Nishi receieved his BD in mechanical engineering from Doshisha University(1981).Since then he has worked in the Research and Development Division at KONICA MINOLTA. He has focused on MEMS ink jet head development.

