The Development of a Static Electricity Actuated Inkjet Head for POS Printers

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Abstract

A static electricity-actuated inkjet head, SEA inkjet head, has been developed for inkjet point-of-sale, or 'POS,' printers. This type of inkjet technology is different from the piezoelectric type. SEA inkjet technology makes possible smaller sized inkjet POS printers with faster print speeds, higher resolution graphics, more precise barcode, 2-color printing, and higher reliability than heretofore.

The SEA inkjet head is fabricated entirely by Micro-Electro-Mechanical Systems (MEMS) processes and its driving voltage is typically 26.5V. The electrostatic actuator comprises a silicon pressure plate and a corresponding transparent electrode parallel to the pressure plate. They are assembled precisely to keep the gap there between to be 180 nm. The ink firing of the SEA inkjet head is responsive to at least to 16 kHz. The durability of the actuator has been confirmed to be more than 10 billion actuations.

In this paper SEA inkjet technology is introduced. And its structure, ink ejection mechanism, fabrication process, driving method and characterizations are demonstrated.

Introduction

Inkjet printers have been widely welcomed in the consumer market. The conventional mechanisms for ejecting ink drops are categorized into two groups. One is a thermal inkjet technology. The other is a piezoelectric technology.[1] The inkjet heads using the above technologies have their own disadvantages. Generally the former consumes too much power and the thermal actuator has a comparatively short life. In the latter case, it is difficult to reduce head size.

We have proposed a SEA inkjet technology which is a novel inkjet head driven by on-demand electrostatic force.[2] And we have also developed a high resolution, large nozzle count, new SEA inkjet head.[3] This inkjet head has several advantages including low power consumption and small size compared to conventional thermal or piezoelectric inkjet heads.

We have developed SEA inkjet technology for a new model of inkjet POS printer. It is installed in Epson's TM-J2000 series inkjet POS printers as shown in Fig. 1. Its head chip is shown in Fig. 2. Crisp inkjet printing, color printing, and low power consumption are strong advantages of SEA inkjet technology for our inkjet POS printer as against direct thermal printers or other thermal inkjet POS printers.

The SEA inkjet head being presented in this paper has 128 face-ejecting nozzles arranged 64 nozzles per column by 2 columns. The concentration of nozzles is 180 nozzles per inch (npi). One column is used for the main color and the other is used for a second color. Customers can choose black, red/black, blue/black or green/black ink combinations.

SEA inkjet technology enables our inkjet POS printer to deliver faster, 2-color crisp printing, use plain paper, and provides high reliability at the same time.

Figure 1. Appearance of Epson's TM-2100 inkjet POS printer

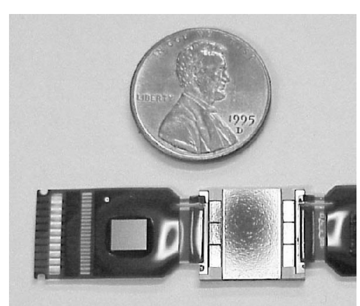

Figure 2. SEA inkjet head chip with FPC attached for TM-J2100

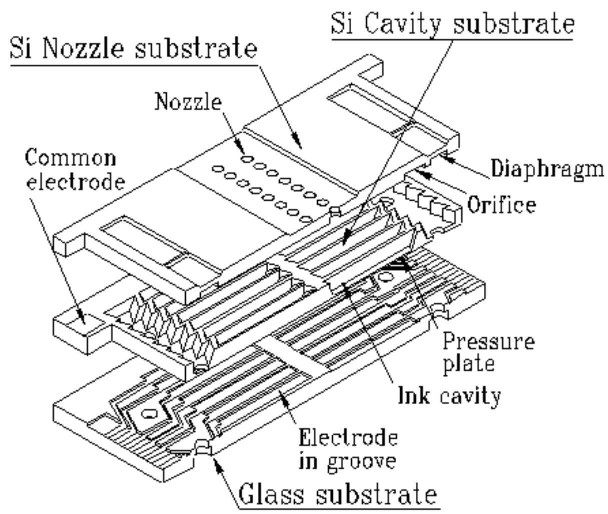

Figure 3.Exploded perspective view of SEA inkjet head chip

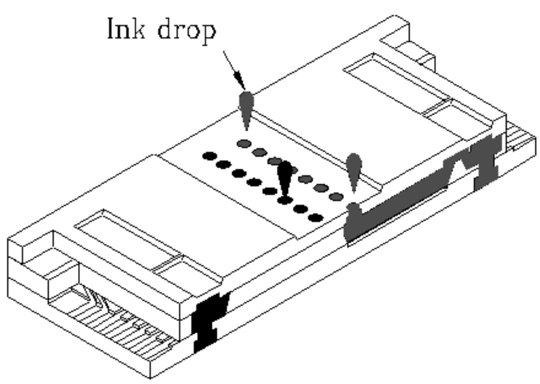

Figure 4. Perspective and partially cross sectional view of assembled SEA inkjet head chip

Structure and Mechanism of Ink Ejection

The SEA inkjet head has a three-layer structure as shown in Fig. 3. These layers are a silicon nozzle substrate, silicon cavity substrate, and glass substrate.

Nozzles, orifices, and diaphragms are formed on the silicon nozzle substrate. Pressure plates, ink cavities, and reservoirs are formed on the silicon cavity substrate. The glass substrate contains grooves and there are individual ITO electrodes in each groove.

The complete appearance of the assembled SEA inkjet head chip is illustrated in Fig. 4.

The ink ejection mechanism operates when an electrostatic actuator generates pressure which effects on-demand ink drop ejection as shown in Figure 5. The electrostatic actuator comprises a pressure plate and individual electrode parallel to the pressure plate in its initial state as seen in Fig. 5 (a). When DC voltage is applied between the pressure plate and the electrode, the pressure plate is deflected, and touches the electrode. Ink flows from the reservoir to the ink cavity through the orifice as in Fig. 5 (b). When pressure in the ink cavity reaches its maximum, the DC voltage is subsequently reduced to 0. The pressure plate vibrates and an ink drop is ejected from a nozzle as in Fig. 5 (c). After an ink drop is ejected, the pressure plate and the meniscus of the nozzle are returned to the initial state.

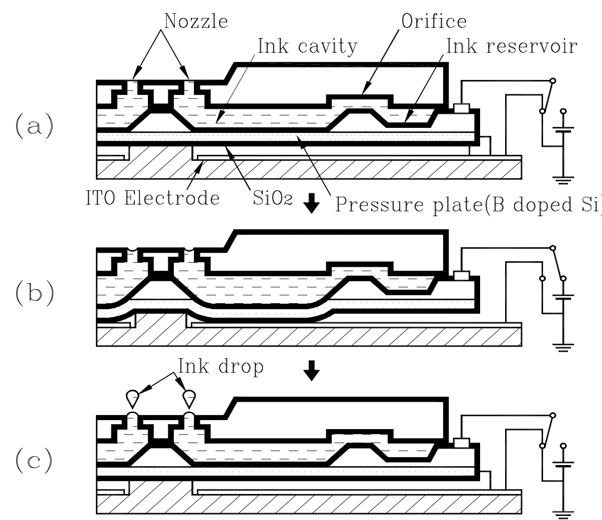

Figure 5. The mechanism of ink ejection (a) initial state, (b) DC voltage is applied between pressure plate and electrode, (c) DC voltage is reduced to 0 and an ink drop is ejected

Design Considerations and Specifications

Inkjet POS printers are designed for use in retail operations such as hotels, fine restaurants, coffee houses, bookstores, and pharmacies. Requirements for these inkjet POS printers are:

1) High printing quality, such as for bar codes
2) High speed printing (high throughput)
3) Small size
4) Low power consumption
5) Long life and durability under heavy-duty usage
6) Low acoustic noise
7) Plain paper printing (versatility)
8) Eye-catching 2-color printing, such as for logos

SEA inkjet technology was also developed and designed to satisfy these requirements. To realize high-speed two-color printing, we designed the SEA inkjet head to have a 180 npi × 2 column nozzle configuration. Each column supplies a different color ink. To achieve high-speed printing, we created a 128 multi-nozzle head designed to enable a maximum driving frequency fd of more than 16 kHz.

At the first stage of design, we determined the main specifications of the SEA inkjet would be:

Typical driving voltage V: 26.5 V
Driving frequency fd: $\leq$ 16 kHz
Nozzle pitch p: 141.2 μm (180 npi)
Ink drop volume w: 20 pl/dorp
Ink drop velocity v: 7.9 m/sec
Ejection direction deviation : $\leq$ 1°

Based on the fabrication process capacity and past data, we fixed and designed the dimensions of both ink pathway and actuator to satisfy these specifications.

Pressure plate thickness T: 2.2 μm
Gap length g: 180 nm
Nozzle diameter Dn: 25 μm
Throat diameter Dn2: 66 μm

Fabrication Process

The SEA inkjet fabrication process consists of a nozzle substrate process, cavity substrate process, glass substrate process, and assembly process. The micro-machining processes for each substrate are described next.

Nozzle Substrate Fabricating Process

Three-dimensional multiple-step structured nozzles are required for straight and high frequency ink ejection. Using deep-RIE, we achieved a precise 3D nozzle shape. A cross-sectional SEM photograph of the nozzle is shown in Fig. 6. After multiple-step deep-RIE, time-controlled wet anisotropic etching is performed from the front side and nozzles were opened. Finally the substrate is wet oxidized to produce a protective thermal oxide.

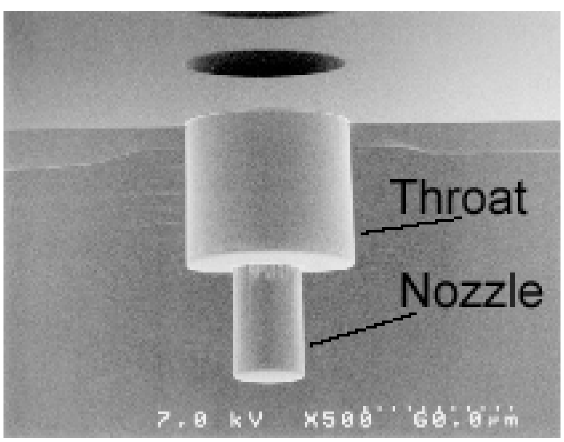

Figure 6. Cross-sectional SEM photograph of a nozzle after multiple-step deep- RIE

Cavity Substrate Fabricating Process

To obtain the required thin and uniform 2μm-thick pressure plate we used boron-doped etch-stop technology. The etch rate of silicon in an alkaline solution decreases when the boron concentration in silicon increases [4]. We selected a KOH aqueous solution as an etchant because it enables higher aspect ratio structures in 110 silicon substrate. The 110-oriented silicon substrate was boron-doped heavily by using a solid boron source and KOH etching was performed. An etch stop phenomenon occurred and pressure plates were formed by the etching stop. A cross-sectional SEM photograph of the cavity substrate is shown in Fig. 7. Subsequently, the substrate was oxidized thermally in dry O_2 to form 110 nm-thick insulator films. Finally, Pt common electrodes were deposited selectively.

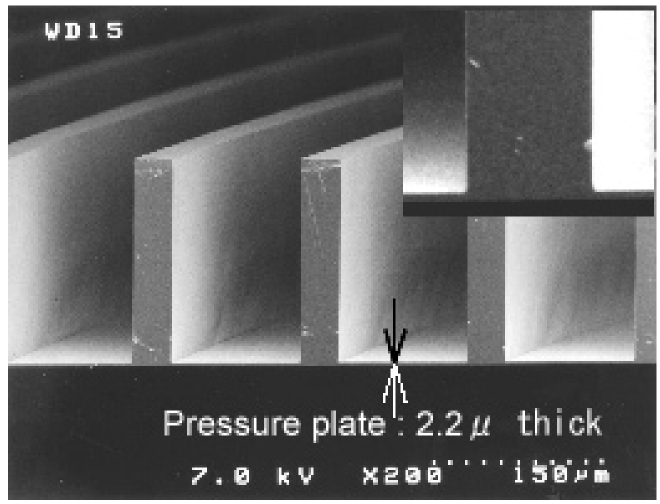

Figure 7. Cross-sectional SEM photograph of the cavity substrate. Pressure plate measures 104μm wide by 2.8mm long by 2.2μm thick. Pitch of ink cavity is 141.2μm.

Glass Substrate Fabricating Process

The glass substrate is etched to have a gap pattern that corresponds to the silicon pressure plate and is formed to have 280 nm-deep grooves. Then a 100 nm-thick ITO film is deposited on the glass substrate and patterned to the individual electrodes. Subsequently the depth of the groove becomes 180nm.

Assemble Process

To form an accurate gap length between the pressure plate and the electrode, the glass substrate and silicon cavity substrate are bonded by the anodic-bonding method. After bonding, the gap is sealed airtight and forms an electrostatic actuator whose gap is precisely 180 nm. Subsequently the silicon nozzle substrate is glued to the silicon cavity substrate. Finally substrates are diced into individual head chips. Each chip measures 13.8 mm wide by 12.4 mm deep by 1.36 mm thick. See Fig. 2 and Fig. 4.

Driving Method

To achieve stable actuator drive we provided a new driving method.[5] This alternative drive control method improves

SEA inkjet head's ink ejection stability. A residual charge is created between the pressure plate and individual electrodes by the number of actuations in the same driving mode. Sufficient ejection of ink droplets cannot be achieved if a residual charge exists. We applied the alternative drive control method in SEA inkjet head to prevent a residual charge and to obtain sufficient ejection of ink droplets. The method has first and second driving modes. In the first drive mode a voltage of a first polarity is applied and in the second drive mode a voltage of opposite polarity is applied.

Through the use of this method, a residual charge can be removed concurrently with ink droplet ejection by applying positive and negative drive voltage pulses.

In the first drive mode, a positive drive pulse (Vp) is applied to the common electrode and a ground potential (GND) is created for the individual electrode. This effects displacement of the pressure plate which causes ink droplet ejection to be performed. In the second drive mode, by creating a ground potential (GND) for the common electrode and by applying a positive drive voltage pulse (Vp) to the individual electrode, ink droplet ejection is again caused.

In order to implement such drive control in a head drive unit, a reverse drive signal FR, whose logic value switches between high and low repeatedly with each data print timing, is sent to the head driver. A logical table indicating the input and output signals of the head driver is shown in Table 1.

Table 1. The logical table for input and output of the head driver to implement the alternative drive control.

INPUT		OUTPUT		Head drive mode
FR	DATA	Individual	Common	
H	H	GND	Vp	Positive drive
H	L	Vp	Vp	Non drive
L	L	GND	GND	Non drive
L	H	Vp	GND	Negative drive

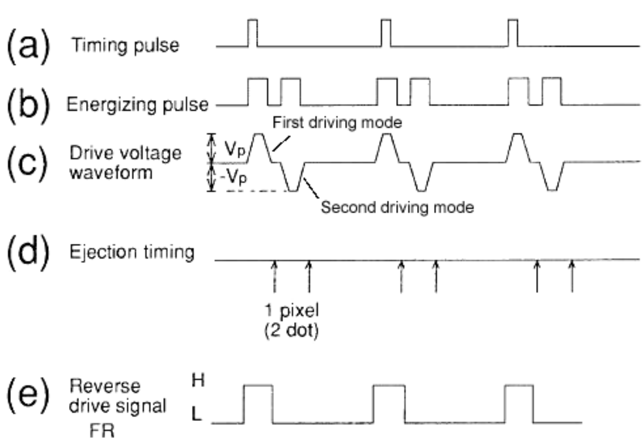

Figure 8. Timing chart showing the alternative drive control

Figure 8 shows a timing chart for the alternative drive control. In the alternative drive control, after the nozzle is driven in the first drive mode, during which a positive voltage Vp is applied, the nozzle is then driven in the second drive mode during which a negative voltage Vp is applied. These two operations of ink droplet ejection cause the printing of one pixel formed on recording paper and composed of the two dots.

Characterizations

Ink drop ejection velocity and ink drop volume deviated slightly up to 16 kHz. Typical ink drop velocity was 7 m/s and its volume was 20 pl/drop at an applied voltage of 26.5V The photograph is shown in Fig. 9 and droplet velocity is shown in Fig. 10. Deviation of the ink drop ejection velocity among 128 nozzles in a head was less than ±5% at 25°C.

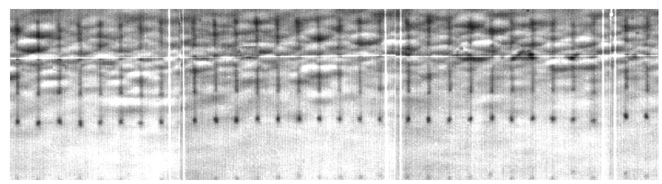

Figure 9. Microscope photograph of ink drop flight. Stroboscopic view of fired drops from all nozzles. Typical velocity of main ink drops was estimated to be 7m/sec, less than deviation.

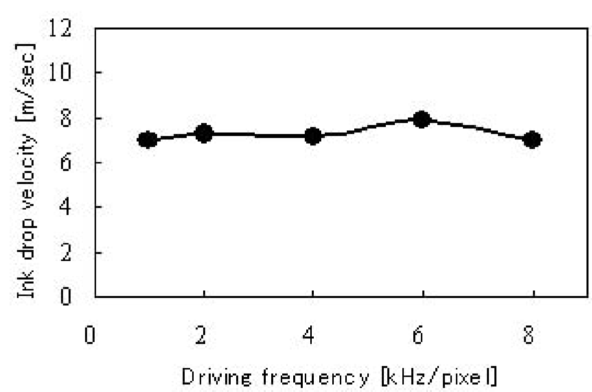

Figure 10. Droplet velocity vs. driving frequency. 1 pixel is composed of 2 dots firing. Thus 8 kHz/pixel is equal to 16 kHz

The average power consumption was measured at 0.5 mW/nozzle and is only one-thousandth of that of a typical thermal inkjet.

Durability tests have confirmed the lifetime of the actuator to be more than 10 billion actuations. We have also confirmed that the ink drop ejection velocity remains unchanged over more than 2.4 billion ink ejections as shown in Fig. 11.

SEA inkjet technology enables a printing speed of 17 l/s in character printing and 50mm/sec in graphics printing, both on 57.5 mm-wide paper. This performance of SEA inkjet technology makes possible the TM-J2000 series inkjet POS printer.

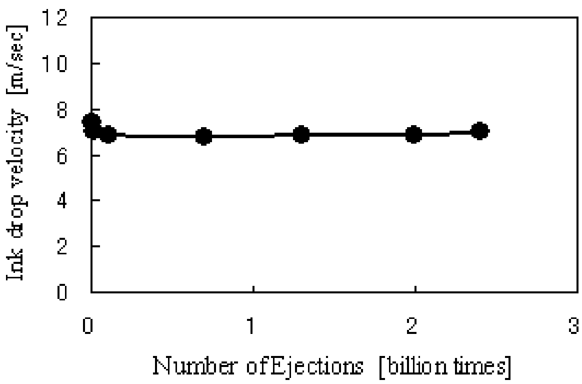

Figure 11. Droplet velocity vs. number of ink ejections. The velocity remains unchanged for more than 2.4 billion ejections.

Conclusion

We have developed a new SEA inkjet head and installed it in new Epson inkjet POS printers. The SEA inkjet head is manufactured by newly developed micro-machining etching technologies. And it is driven by a new driving method. SEA inkjet technology marks the realization of inkjet POS printers featuring faster printing speeds, crisp 2-color printing, small size, less power consumption, and the greatest durability of any such printer in the world.

We have determined that still higher frequency ink ejection of fine droplets and full color inks in smaller dimensions are the next goal of SEA inkjet technology.

References

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Biography

Masahiro Fujii is a manager in the Production Engineering & Development Division of Seiko Epson Corporation. He received his B.E and M.E. in mechanical engineering from Kanazawa University, Japan, in 1984 and 1986 respectively. He has worked with mini-printer mechanisms and their key devices at the System Device Division for fifteen years. He is currently in charge of developing, designing and evaluating inkjet heads, especially those using SEA inkjet technology. His recent interests are MEMS technology, its contribution to inkjet process, and its production processes.