Design and Fabrication of the Monolithic Inkjet Print Head

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Abstract

A monolithic inkjet print head was designed and fabricated with back shooting type of thermal bubble nucleation in this study. MEMS fabrication processes are applied to define the ink firing chamber, feed channel and the orifice plate within this new micro injector structure. In this study, printing resolution of this monolithic inkjet head is 600 dpi and the diameter of nozzle orifice is about 14 μm with thickness of 30 μm. Both the silicon dry and wet etching processes are applied to the fabrication of orifice plate with the control of thickness within ±4 μm. The major advantage of this monolithic inkjet head is free of the assembly processes of inkjet device and the process throughput is improved. Operating frequency of the monolithic inkjet print head developed in this study is 19 KHz. By the optimization design of this monolithic inkjet print head could provide better printing quality than commercial ones.

Introduction

For a liquid ejector, there are two methods to drive a droplet. One is thermal bubble type. The other is piezoelectric type. Recently, a liquid ejector, which makes use of thermal energy as a driving force, has become a commercial product. And the process of it has been widely known and researched. For a traditional thermal bubble inkjet head, there are four main components which have to be fabricated and assembled precisely especially for the process of a thermal resistor chip, the manufacture of nozzle plate, and the package between nozzle plate and chip.

Nowadays, the main stream for a desktop printer is to do anything possible to reduce the production cost and increase the density of heater arrangement. Based on this concept, there are two issues that have to be concerned. One is that it would be more difficult to put the nozzle on the heater precisely. During assembly of the nozzle plate and the chip, precise alignment is required, thus the time of assembly is increasing. Furthermore, assembly takes place individually, thus reducing the efficiency of the manufacture and increasing the cost. The other is that it would be more difficult to form ink slot based on reducing the chip size to lower the cost. For a color inkjet printer with high resolution, three ink slots are formed on one chip. To reduce the area of the chip, the ink slot is a narrow and long rectangle, thus increasing the difficulty of the formation thereof. The sandblast process is introduced to form a through slot that passes the chip for ink feeding. Contamination and crack of the silicon wafer are commonly seen during the sandblast process. In addition, the sandblast ink slot on a chip increases the difficulty of the circuit layout.

Recently, there is a trend for high speed, high resolution, and high printing quality on photo. But for industrial application, it needs high flexible to eject each kind of working fluids and high working life. The highest physical resolution is only 1200dpi in commercial product, but the printing resolution could be 4800dpi by the compensation of software. This compensation mechanism will lower the speed of printing because it needs to print on a local area again and again to reach its high resolution that it claims. Therefore, for looking after high speed and high quality, the physical resolution should be raised to a higher level. But there are still three requirements even if the physical resolution is 600dpi.

a. The inaccuracy of alignment should be less 2 μm.
b. The life of heater should be raised 10 times than that of traditional heater because the size of droplet continues shrinking and it will take more time to complete the compensation.
c. The flow resistance of micro channel increases and the efficiency of bubble decreases. These two factors will affect the frequency of refill of ink.

Based on these reasons, there have been some monolithic designs of inkjet print head to overcome these problems.[1-5]

We provide a design of back-shooter inkjet head based on MEMS technology. This concept integrate the MEMS' technology, integrated circuit, and electroforming technique into this design to fabricate heater element, micro channel, nozzle array and driving circuit. It will decrease the inaccuracy of alignment between the nozzle and heater and elongate the life. The structure disclosed in this paper replace the bonding process by the 3-dimension electroforming technique. The ink feed slot formed by electroforming is separated from the substrate, this makes the circuit layout more flexible and prevent from the contamination and crack during sandblast process. The electroforming structure combines the ink feed slot, the ink flow channel and the ink-firing chamber. In other words, there is not had polymer barrier on the inkjet head that may be corroded by solvent while the inkjet head is applied to the industry applications. The alignment mismatch between the chip and nozzle plate are also reduced because the electroforming pattern is defined by photolithography process, which could control the mismatch less than 1 µm. In this structure, the batch processes are used and which could be saves more time.

Design of the Monolithic Print Head

According to those discussion described above, there are three issues which should be solved, and we have to think of some ideas which could be applied to design. The first one, which could avoid assembling the nozzle plate with chip, is to fabricate the nozzle on the chip directly. But it will change the direction of the droplet differing from that of a traditional top-shooting inkjet head. Therefore, this is a design of back-shooting inkjet head whose direction of bubble formation is inverse to that of flying droplet. Second, which could avoid the sandblast process to etch through the chip and generate some cracks, is to replace the method of liquid supplement which supplies ink from the back side of a chip with a new one which supplies ink from the top side of a chip. Third, which could avoid some special working fluid to corrode the micro channel and ink chamber, is to make use of electroforming technique to form a metal structure.

Therefore, as shown in Fig. 1-1, the first step is to manufacture some specific thin films to define heater elements and control circuit on the thermal bubble ink jet chip. These thin films should contain a thermal barrier layer that can concentrate the thermal energy on working fluid, a conductive layer that is responsible for sending electrical single to heater elements, a thermal-resistor layer called heater element that is the key component to generate bubble, and a passivation layer that is a multi-function part which has to isolate those layers conducting electric current from liquid and deliver thermal energy.

According to the first idea, the thickness of the local area of the nozzle position has to be reduced to a specific value to 20 ~ 50 µm. The driving force cannot eject droplet until the thickness is diminished to a specific value. Therefore, as shown in Fig. 1-2, we make use of etching technique to complete this requirement. Besides, for concentrating most driving force on the droplet, the position of the nozzle has to be placed near the heater. As shown in Fig. 1-3, the nozzle is formed by dry etching instrument, such as ICP (Inductive Coupled Plasma).

According to the second and the third ideas, the mechanism of supplying liquid can be made of metal by electroforming technique and the direction of it is from the topside of the chip (Fig. 1-6). The firing chamber with micro channel and the mechanism of supplying liquid can be defined at the same time by making use of three-dimensional sacrificial layer composed of photoresist (Fig. 1-4). After electroforming process (Fig. 1-5), the sacrificial layer can be removed (Fig. 1-6). Finally, a high-resolution monolithic inkjet head is completed without any assembling process.

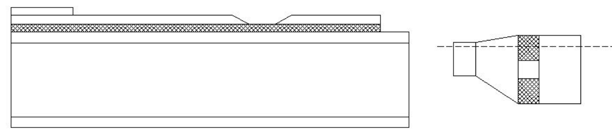


Figure 1-1. Thin film process.

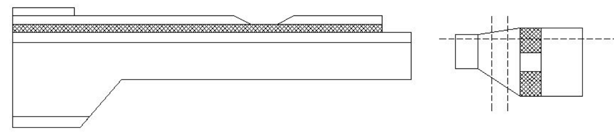


Figure 1-2. Reduce the thickness of silicon substrate.

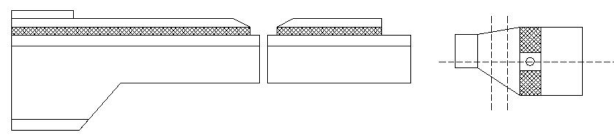


Figure 1-3. ICP etching to form nozzles.

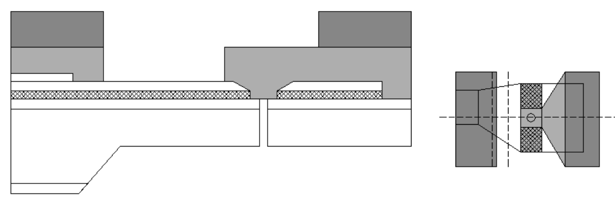


Figure 1-4. 3D sacrificial layer definition.

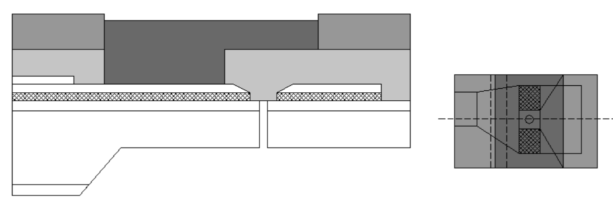


Figure 1-5. Electroforming process.

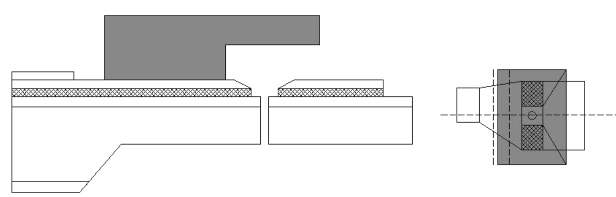


Figure 1-6. Removing the sacrificial layer.

In this study, the total resistance of the loop is about 37Ω. These two heaters are parallel to form an individual actuator and the size of the heater is 15 × 30μm^2.

Fabrication of the Monolithic Print Head

In this study, the etching processes were carried out on a double side polished (100) P-type silicon wafer with 400 μm thickness, and depositing thin films on one polished side and deep chemical wet etching on the other one. The etching solution is a TMAH solution with 25% in weight percentage, which is added with isopropanol. For manufacturing the ink jet chip with driver circuits, it needs a silicon membrane with 30μm thickness and good surface quality of the etched surface to provide good status of ejection droplets. The standard of this etching mechanism is that the deviation of the etching depth is within ±2 μm. And we expect that the surface roughness could be controlled under some specific value. After a progress of etching technique, the etching depth deviation can be controlled under 4 μm, and the values of the depth are arranged from 364~368 μm (as shown in fig. 2). On the other hand, the roughness of etched surface is from 34 ~ 45 Å (as shown in fig. 2).

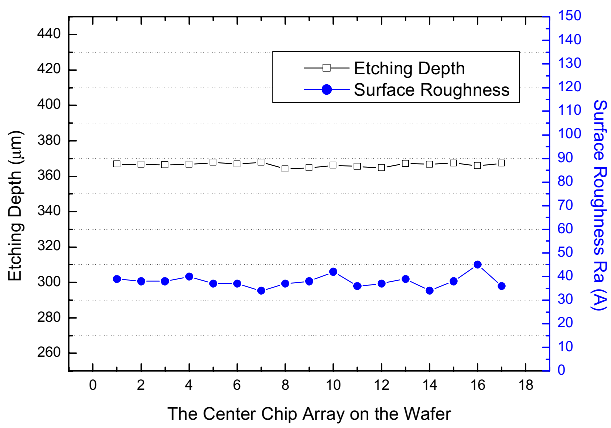


Figure 2. The etching depth and roughness

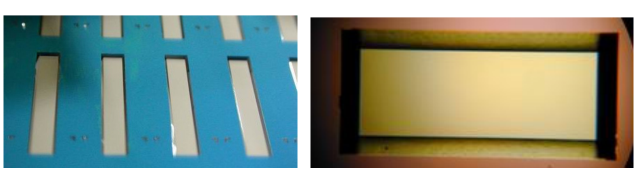


Figure 3. Free pyramid etched surface.

This etched surface is not only free-pyramid, but also ultimately smooth like a polished surface. Under the same method of measurement, the roughness of a polished wafer is about 30 Å. This measurement instrument whose method belongs to contacting the surface like α-stepper, is very sensitive to surface condition. And there is a standard glass ball with 40 Å to modify the sensitivity. Therefore, these results could be trusted. As shown in figure 3, there are no pyramids in the etched surface.

There is another important issue that could not be ignored. This issue is how to decide the timing to stop etching if we expect that the thickness of the nozzle is 30 μm. However, there is no etching stop layer to reach this requirement and 75% of the etchant is water which is so easy to vaporize at 80°C condition that the etching rate could be unsteady. So the etching rate has to be controlled very stably during the process. As shown in figure 4, we can find that the etching rate is from 22.73 to 24.36 μm/hr in 14 hours. The variation is about 1.63 μm/hr. In the future, this is a qualified stability to manufacture the inkjet print head.

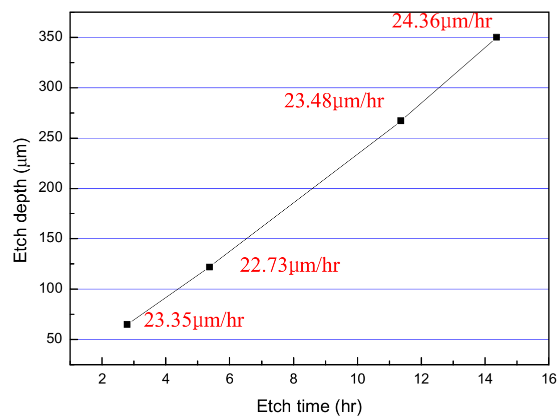


Figure 4. The etching rate of the chemical wet etching.

After the thickness definition of the silicon plate, the next step is to drill through the silicon wafer by using the ICP dry etching to defined nozzles. For a better nozzle structure, the etching process will be carried out on the topside of silicon wafer. We use the photoresist of AZ4620 as an etching mask to define the pattern of nozzle. As shown in figure 5, the nozzle has to be defined precisely between two heaters. The depth of the nozzle is about 30μm, and the diameter of the nozzle is about 14 μm.

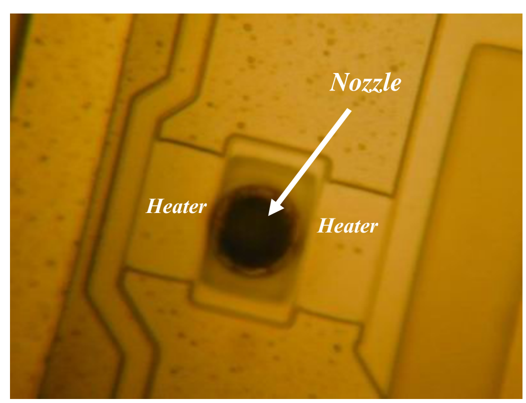


Figure 5. ICP to form nozzles

The next step is to define the micro channel and ink chamber. The MESD (Multi Exposure Single Development) technique is developed to form the 3-dimension sacrificial structure for the electroforming process. Two kinds of photoresist are used to form the structure by laminating. The composition of these two types of photoresist is the same but with different thickness. The thickness of first photoresist is about 20μm and which laminating onto the substrate, after the first laminating step, the photoresist should be exposed by UV light source for curing purpose. The thickness of second photoresist is 40μm and which laminating onto the first photoresist, and the substrate is exposed under UV light again. After two times of the exposure steps, the substrate is then proceeding with the development step. As shown in figure 6, the pattern that we desired to achieve will appear after the development step. After the 3-dimension sacrificial structure is formed, the electroforming process is used to define the ink feed slot, ink flow channel, and the ink-firing chamber. The sulfamate nickel is used as the electrolyte here, the temperature of the electrolyte is about 55°C, and the current density is about 10 ASD. The electroforming process will be stopped once the deposition thickness reach about 50μm. Finally, the sacrificial layer will be stripped and leave the nickel structure on the substrate.

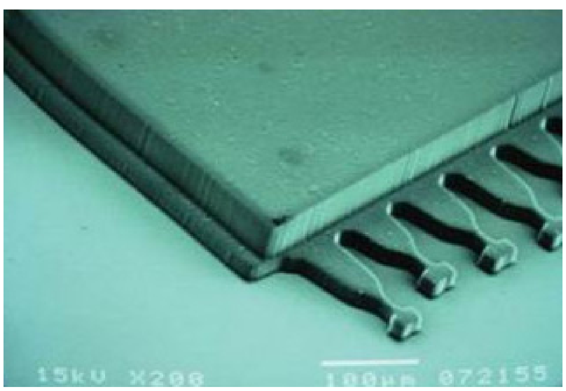


Figure 6. 3D sacrificial structure

Results

In this study, we will use two methods to evaluation of this ink jet head. First, used the open pool observation to observe formation of the bubble and the bubble growth cycle. Second, the behavior of droplet ejection was also observed by image capture system. In this study, the bubble formation was shown in figure 7. The bubble occupy the firing chamber, which value of apply voltage is called begin voltage (V_b). The V_b of this design is about 7.4V, while the firing frequency is 5KHz and pulse width of apply signal is 2.4 μSec.

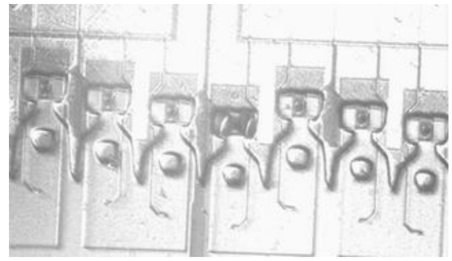
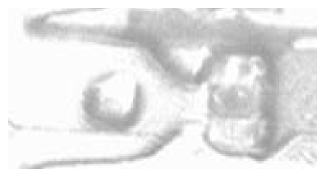


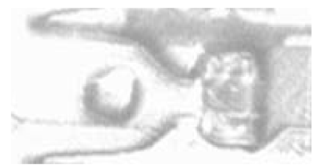
Figure 7. Bubble formation by open pool testing

(1) Observation of Bubble Formation

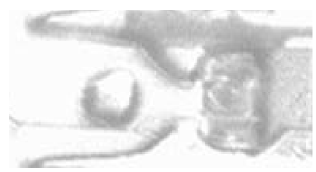
In this study, we observed the cycles of bubble formation by image capture system, as shown in figure 8(a), the bubble nucleation at apply voltage of 7.1 volt. In the figure 8(b) to 8(d), the bubble volume is increasing with the apply voltage increasing.



(a) 7.1V



(b) 7.2V



(c) 7.3V

(d) 7.4V

Figure 8. The formation of bubble with different apply voltage.

After that, we would like to observe the whole process of bubble formation. It would be from the nucleation to dissipation. The operational parameters will be fixed at apply voltage is 7.4 volt, operation frequency is 5 KHz, and pulse width of signal is 2.4 μSec. In this study, the bubble nucleation at 2 μSec, and bubble grown up. At the 5.8 μSec, the volume of bubble reaches to maximum. Therefore, the time of bubble formation is 5.8 μSec in this study. Continuously, the bubble is dissipating and which disappear at 7.4 μSec.

(2) Observation of Droplet Ejection

In this study, package of the monolithic ink jet print head was shown in figure 9. We would like to know the behavior of the droplet ejection and its life under severe driving conditions.

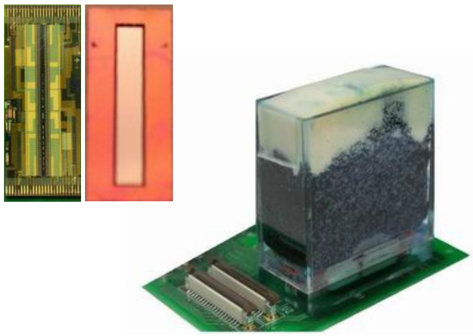


Figure 9. The package of monolithic ink jet print head.

First, we would like to observe, measure and estimate the velocity of droplet and the volume of droplet. In the figure 10, the behaviors of droplet ejection were shown and the operation frequency is 5KHz.

From the results of figure 10, computing the velocity of droplet is 10m/s, and estimating the volume of droplet is about 4pl. The velocity of droplet is lower than the same specification of commercial ink jet print head because of its back-shooting design. And there is a satellite droplet behind the main droplet.

In the figure 11, the monolithic ink jet print head is operation in the various operation frequencies. In this study, the highest operation frequency is 19KHz, and this nozzle can be fired continually at least than half hour. In the other words, the life of monolithic head will longer than 3.42×10^7 times.

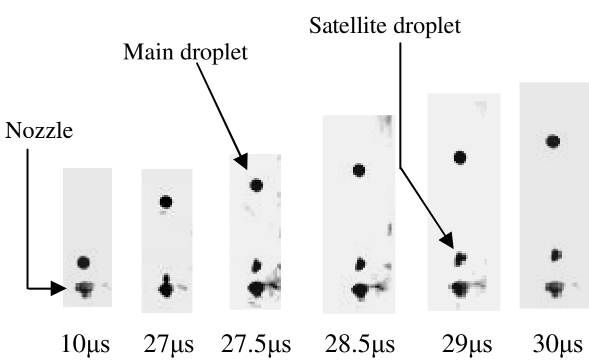


Figure 10. Behaviors of droplet eject at 5KHz.

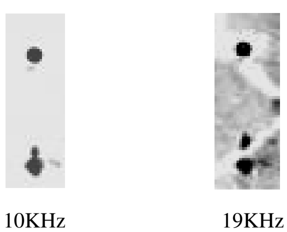


Figure 11. Behaviors of droplet eject in various frequencies.

Summary

An innovative monolithic inkjet print head has been fabricated and tested. Fabrication process combines the semiconductor thin film process and micro machining techniques of the (100) silicon wafer. The 3-dimension electroforming process is also involved here to replace the sandblast and chip bonding process that commonly used in commercial inkjet head. Optimization of this structure will be continued to achieve a high resolution, high nozzle density and high print quality inkjet print head in the future.

Reference

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Biographies

Chi-Ming Huang joined the printing Technology Division of OES/ITRI in 2002. He received his M.S. degree from Institute of Applied Mechanics of National Taiwan University, Taipei, Taiwan. His current research includes MEMS technology, micro fluid control, thin film process and the study of monolithic inkjet head.

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