# Novel Monolithic Micro Droplet Generator

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## ABSTRACT

A novel monolithic off-shooter droplet generator has been demonstrated. The design, fabrication, bubble formation and droplet injection are described in this paper. It is different from the conventional droplet generators of top-shooter, side-shooter and back-shooter for injection. The droplet ejected from such off-shooter generator has the merits of straight trajectory with satellite improvement by two bubbles cutting and strong structure of stacked metal-polymer or polymer-polymer layers by integration of two-photoresist lithography and electroforming technologies. It is potentially used for inkjet printing, LCD color filter dispersion, microarray for bio application and so on.

***Keywords***: monolithic, droplet generator, SU8, MEMS

## 1 INTRODUCTION

The conventional inkjet chip needs complex alignment and bonding process to stick the nozzle plate and heating chip together [1]. It takes long time, high cost and much lower alignment resolution. Some monolithic inkjet chips [2-6] fabricated by the MEMS technology can improve the above drawbacks but suffer from the nozzle membrane broken during processes. Chen et al [2] used the method of anisotropic wet etching and chemical vapor deposition (CVD) sealing process to form the side-shooting nozzle plate. It requires the CVD high temperature process and the strength of sealed Si-based nozzle plate is a challenge. Westberg and Andersson [3] used CMOS process in combination with bulk etching and aluminum sacrificial etching to fabricate a monolithic CMOS compatible inkjet chip. However, the device was rather fragile and hard to handle during the process. Tseng et al [4] designed a monolithic microinjector with virtual chamber neck for satellite improvement but it still encountered the problem of membrane broken during processes.

In this paper, we report this monolithic droplet generator in combination of the advantages of conventional and monolithic inkjet technologies by changing the conventional inkjet heater shape from square into ring and integrating the electroforming and two photoresists (SU8 or JSR) technologies to form the strong metal or polymer nozzle plate. It avoids the membrane broken problem and simplifies process procedure with low cost and good droplet properties.

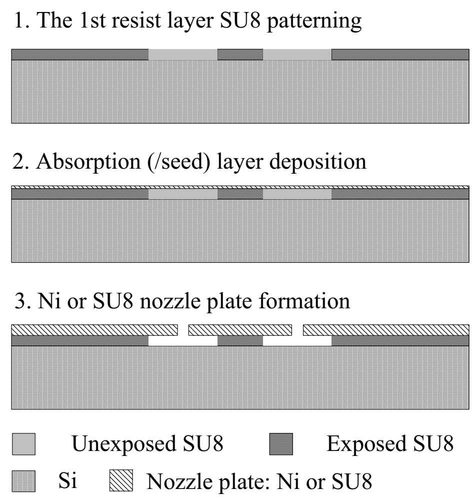
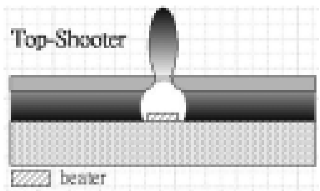



Figure 1 Schematic process flow of the combination of thick resist and electroforming technologies for the formation of ink chamber and nozzle plate of the monolithic inkjet chip.

## 2 EXPERIMENTAL PROCEDURE

Figure. 1 shows the schematic process flow of combination of thick resist and electroforming technologies for the formation of ink chamber and nozzle plate of the monolithic inkjet chip. It integrates two kinds of thick photoresists (SU8 and JSR) lithography process and one-step nickel electroplating process to form the chambers and nozzles of monolithic inkjet chip. The first thick resist of SU8 of about 35 μm is used for the structure formation of ink channel and chamber. It is coated and patterned on the substrate but not developing. A light-absorbing CK-6020L resist layer is followed to coat on the SU8. The following process depends on the kind of nozzle plate material. The first kind of nickel metal nozzle plate is performed by second thick resist JSR mold patterning on the first SU8 chambers, followed by nickel electroforming and non-exposure resist stripping. The second kind of polymer nozzle plate utilized second thick resist of SU8 material to replace nickel metal. Second thick SU8 resist was patterned by photolithography and the overall non-exposure

SU8 was removed to form the monolithic SU8 nozzle plate. The quality of thick resist and electroformed Ni or SU8 nozzle plate are examined in optical microscopy (OM) and scanning electron microscopy (SEM). The thermal bubble formation in open pool test of heating chip was observed by a flow visualization experiment in this study. The droplet injection was also examined in this system. The function synthesizer produces two synchronized periodic pulses for the heating element and the LED stroboscope. The delay time is adjustable to freeze different stages of bubble formation to characterize its formation sequence.

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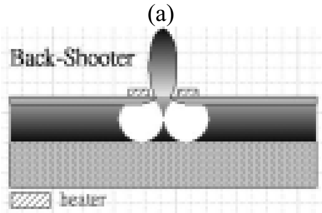


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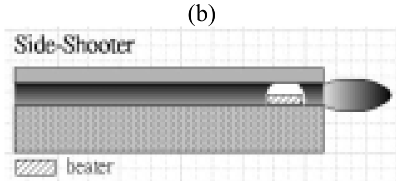
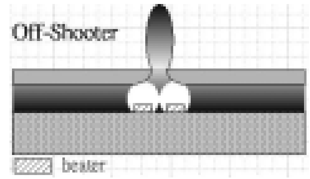



(c)

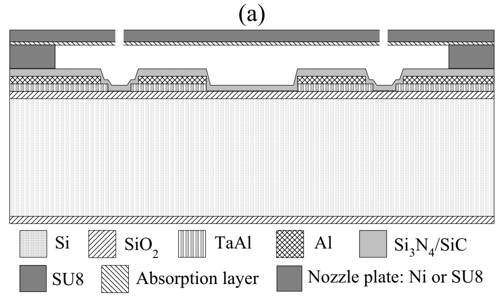
Figure 2 Schematic traditional three types of droplet generators: (a) top-shooter, (b) back-shooter, and (c) side-shooter

## 3 RESULTS AND DISCUSSION

Figures 2(a)- 2(c) show the schematic traditional three types of droplet generators: (a) top-shooter, (b) back-shooter, and (c) side-shooter, respectively. The top-shooter droplet generator means the droplet injected in the same direction as the thermal bubble formation while the back-shooter with the opposite direction of droplet and bubble. Our design and cross-section of off-shooter droplet generator are shown in Figures 3(a) and 3(b), respectively. The off-shooter means the droplet injecting direction is a little shift from the two thermal bubbles formed by the ring heater of inkjet chip. The cross-sectional structure of generator includes the TaAl heater on $SiO_2$/Si substrate and passivated with $Si_3N_4$/SiC as well as Al conductor, SU8 chamber and nozzle plate.



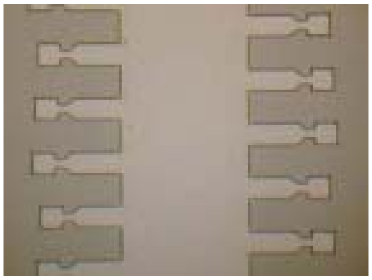

(a)



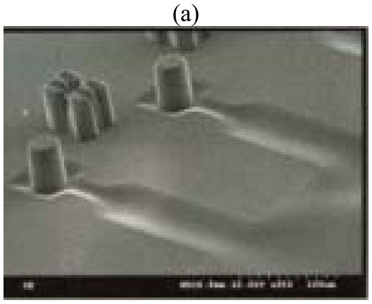

(b)

Figure 3 Novel off-shooter droplet generator: (a) schematic diagram and (b) the detailed cross section of generator with TaAl heater on $SiO_2$/Si substrate and passivated with $Si_3N_4$/SiC as well as Al conductor, SU8 chamber and nozzle plate.

Figures 4(a)- 4(d) show the experimental result of SU8 structure, JSR molds, Ni and/or SU8 nozzle plate respectively by integrating the two thick resists and electroforming technologies for the formation of ink chamber and nozzle plate of the droplet generators. The structure layer is formed by first thick resist SU-8 due to its superior properties [7] while metal or polymer nozzle plate is formed by electroforming and second thick resist process. For stacked metal-polymer ie Ni-SU8 structure, the second JSR thick photoresist is used for forming the electroplating mold of nickel nozzle plate due to easily removal by acetone [8], followed by nickel electroforming and stripping overall non-exposure resist. For stacked polymer-polymer ie SU8-SU8 structure, the second thick SU8 resist is used for total SU8 polymer injecting microstructure, instead of both JSR resist and nickel electroforming process. The light-absorbing CK-6020L polymer layer is coated between two photoresist layers for protecting the SU-8 layer from overheating during the metal seed layer deposition and over-exposure during the second thick resist lithography process. Good quality of structure at each step during the fabrication of monolithic chip has been achieved. The visualization of the bubble formation by conventional square- and off-shooter ring-type heater are compared using open pool test as shown in Figures 5(a) and 5(b), respectively. The bubble starts to form around 2 μs after the beginning of the heating pulse. A single bubble is formed on the square heater at the off-center position while Two oval bubbles at the ring heater center, rather than a single 'donut' bubble, are generated by the ring heater. The two oval bubbles will generate the droplet with straighter trajectory than the single bubble at off-center position.



(a)



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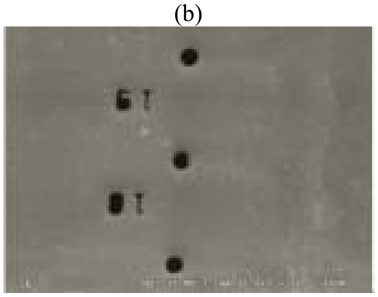

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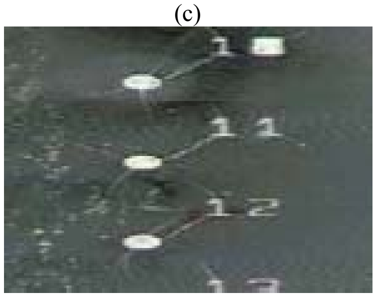
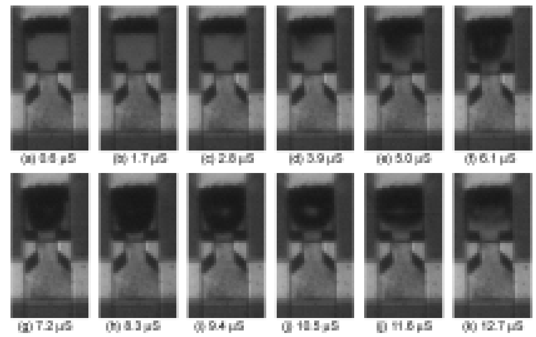


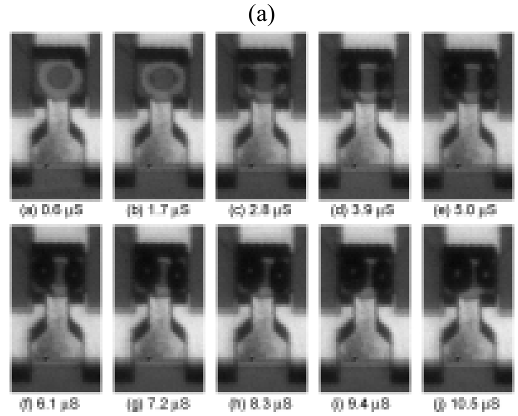
(d)

Figure 4 Micrographs of (a) SU8 structure, (b) JSR molds, (c) Ni nozzle plate, and (d) SU8 nozzle plate during the monolithic process.

Figures 6(a) and 6(b) show the temperature distribution of ANSYS simulation for square-type heater and ring-type heater after voltage applied, respectively. The highest temperature region is formed at one central area of square-type heater to produce one thermal bubble nucleation and growth. The real bubble position of square heater in Figure 5(a) is away from the center due to the fluidic flow direction and surface-dependent nucleation. The position away from the ink inlet neck is with lower cooling effect to get higher temperature than the inlet neck. But the highest temperature region at ring-type heater is formed at two central areas to produce two thermal bubbles as shown in Figure 5(b). The two thermal bubbles will cut the droplet injection with straight trajectory and satellite improvement. Figure 7 shows the picture of droplet injected from off-shooter generator. Good quality of droplets have been generated in this novel droplet generator.



(a)



(b)

Figure 5 Time series of bubble formation with: (a) square-type heater and (b) off-shooter ring-type heater. A single bubble is formed on the square heater at the off-center position while Two oval bubbles is formed at the ring heater center.

## 4 SUMARRY

A novel monolithic off-shooter droplet generator has been designed and fabricated by changing the conventional square heater into ring one and integrating two thick resist photolithography and one-step electroforming technologies for the generator formation. This process integration based on silicon micromachining has the advantages of accurate alignment of nozzle plate to the substrate, simple process and low cost in comparison to the conventional hybrid technology of nozzle plate attached to the substrate. A light-absorbing polymer layer between two thick resist layers is good for protecting the first SU8 layer from overheating or over-exposure during the metal seed layer deposition and the second thick resist lithography process. The thermal bubble formation and droplet injection are also realized in this study. The off-shooter ring-type heater with two thermal bubbles will inject the droplet with straight trajectory and satellite improvement by bubble cutting mechanism.

## ACKNOWLEDGEMENTS

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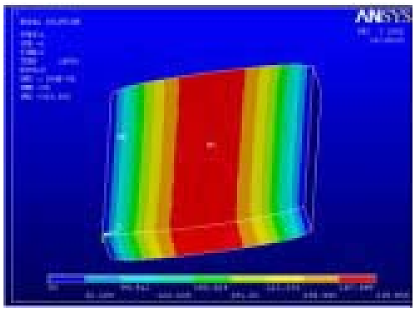


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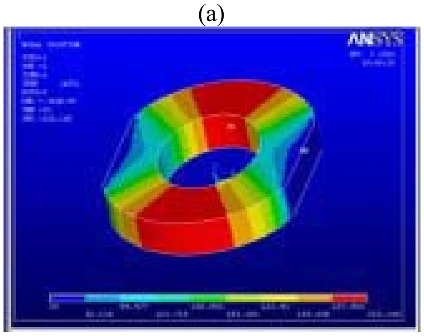


(b)

Figure 6 Temperature distribution of ANSYS simulation: (a) square-type heater and (b) ring-type heater after voltage applied.

Figure 7 The picture of droplet injection from off-shooter generator.

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