The Flow Dynamic Simulation and Experiment of Piezoelectric Printhead

Wei-Hsiang Lai[1], Yeong-Jen Wu[2]*
Institute of Aeronautics and Astronautics, National Cheng Kung University,
No.1, University Road, Tainan 701, Taiwan

whlai@mail.ncku.edu.tw

Abstract

This paper investigates the flow dynamic behaviors with respect to different frequency of the piezoelectric print head by using the way of simulation and experimental method. Its geometric model is divided into three zones for easy description as channel zone, nozzle zone and ejection observing zone. The length, width and orifice diameter of the micro-channel are 2,000µm, 400µm and 30µm, respectively. The moving wall is located on the top wall of the channel zone in order to obtain proper condition for single drop generation; we applied the numerical simulation by commercial CFD software CFD-ACE+ 2006. The most important purpose of this study is to find out the optimal frequency to eject droplets periodically and control the volume of droplet ejection which may provide the reference for experimental work later on. The results show that by fixing the contact angle and frequency from 2,000Hz to 20,000HZ. After simulation analyses, this paper also discuss about piezoelectric print head manufacture. Aiming piezoelectric print head do a series test, discussing about frequency effect to the print head.

Key words: piezoelectric printhead

1.Introduction

In 1987, Dabora etc. disturb the liquid jet making single droplet, they mode derivation of the relationship between frequency, liquid velocity and droplet size as eqn.1.

$$F = u_j / (4.08\, d_j) \qquad (1)$$

In 1997, Brenn etc. derivate the theory of droplet by nozzle size, frequency, liquid velocity and droplet size as eqn.2.

$$D = (3ud^2 / 2f)^{1/3} \qquad (2)$$

Where f is frequency, u_j is liquid velocity, d_j is nozzle diameter.

This kind of print head are continues type and the other way of inkjet printing is drop-on-demand inkjet methods, the drops are ejected only when they are required in imaging on the media in this way. There are about four kinds of drop-on-demand inkjet technologies, *i.e*., acoustic, electrostatic, thermal bubble and piezoelectric inkjet technologies. Today, the popular printing techniques are thermal bubble inkjet and piezoelectric inkjet technologies. Thermal bubble inkjet ejects ink by heating the working fluid to its boiling point to create bubble to push against the droplet out of the orifice, and then the ink refills when bubble breaks. The thermal bubble inkjet technology is considerably stable and low price so that it grows fast. However, this actuating way limits its ejecting frequency. Necessity to heat the working fluid also limits its working fluid variation. And the heat plate maybe not heating uniformly will influence the ejecting angle of ink.

The piezoelectric inkjet has not the shortcomings of thermal bubble inkjet, so it has more potential in the future print market. These kinds of printers, on the application of voltage pulse, the drops are ejected by a pressure wave created by mechanical motion of piezoelectric ceramic actuator. Piezoelectric operational modes in inkjet technologies can be further classified into four types, *i.e*., squeeze mode, push mode, bend mode and shear mode. Now days, printer has been used popularly in commercial inkjet. Inkjet printing have been used in many application areas, such as office printing [1-2], bio-fluid printing, IC cooling and direct writing[3], even liquid crystal display spreading using print head technology to replace yellow light process[4]. Reliable, high performance and low-cost inkjet devices are always in great demand. Inkjet printing technology also has been explored to be applied to flat panel displays [5] fabrication. Organic light-emitting diodes (OLEDs) are one of the most promising technologies for the future. However, due to limitation on the solution selection, they are usually fabricated by using thin film deposition with an evaporation process and subsequent patterning through lithography. The processes, along with the required masks, are very expensive. Great benefits will be obtained if arrays of organic light-emitting materials can be deposited directly by inkjet printing methods. The current exercise for polymer light emitting diodes (PLEDs) is deposition through spin coating. With the application of inkjet printing technology, it is possible to deposit tiny pixels of red, green and blue elements to produce the color filters. Compared with the spin coating process, inkjet printing technology has the benefits of high resolution, low cost, simpler processing, a high rate of materials utilization and the capability to produce large panels. Inkjet printing technology also provides a unique process for micro-lithography and the fabrication of micro-lens arrays as well as complex three-dimensional structures [3].The most important issues of this study is to find out the optimal inlet velocity for print heat manipulation and the inkjet print head generate enough pressure to eject droplets periodically and control the volume of droplet ejection. To demonstrate the importance of the design parameter, computational fluid dynamics with Volume Fraction of Fluid (VOF) is used to simulate the instantaneous meniscus shape, as well as velocity and pressure filed within the inkjet print head.

2. Simulation Model Setup and Numerical Tool

2.1. Piezoelectric print head model

In flow model, the governing equations for the flow model represent mathematical statements of the mass and momentum conservation laws of physics for flow. These two laws can be used to develop a set of equations (known as the Navier-Stokes equations) .

This study refers the piezoelectric print head model of Xaar company[10]. The geometric model is also divided into three zones for easy description. They are channel zone, nozzle zone and ejection observing zone, as shown in Figure 1.

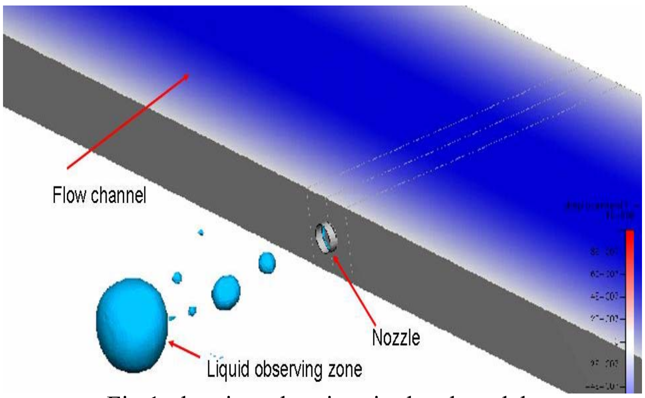
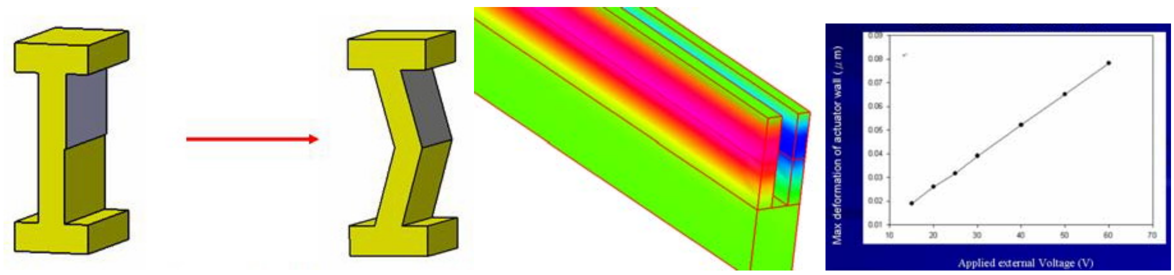


Fig.1. the piezoelectric print head model..

The length, width and orifice diameter of the micro-channel are 2,000μm, 400μm and 30μm, respectively. There is a fixed velocity flow from the inlet to the right side of the channel. On the top of channel is piezoelectric actuator which compresses the working fluid to eject from the nozzles. This previous design is simulated as the moving wall. The piezoelectric ceramic actuator simulations [11] are shows in Figure 2.



(a) (b) (c)

Fig.2. (a) the ideal of piezoelectric wall deform (b)the simulation of piezoelectric channel (c)the relation between voltage and deformation

The vibration displacement y on the moving wall is defined as:

$$y = amp \bullet \sin(2\pi F t) * \cos(\frac{x - L/2}{L}\pi) \qquad (3)$$

Where x and y are local coordinates of moving wall. Symbol y, amp and F represent radius direction displacement, amplitude and frequency of vibration on the moving wall.

2.2 Numerical tools

In this study, the simulation was performed with the CFD-ACE+ software (CFD Research Corporation, Huntsville Alabama), a multi-physics package based on the Finite-Volume methods. The program was run on an Intel core2 duo 2.34GHz processor with 3GB of RAM memory. The mesh-independent test runs were verified with the 11,065 cells. The time for each run spanned from 36 hours up to 48 hours.

Flow model with moving wall boundary and volume of fraction (VOF) in CFD-ACE+ software will be used in the simulation. In flow model, the governing equations for the flow model represent mathematical statements of the mass and momentum conservation laws of physics for flow. These two laws can be used to develop a set of equations (known as the Navier-Stokes equations) for CFD-ACE+ to solve numerically.

(a) Mass Conservation

Conservation of mass requires that the time rate of change of mass in a control volume be balanced by the net mass flow into the same control volume (outflow - inflow). This can be expressed as:

$$\partial\rho/\partial t + \nabla \cdot (\rho V) = 0 \qquad (4)$$

Where ρ is the density of fluid and V is velocity vector of the flow field.

(b) Momentum Conservation

Newton's second law states that the time rate of change of the momentum of a fluid momentum equation is found by setting the rate of change of x, y, and z-momentum of the fluid particle equal to the total force in the x, y, and z-direction on the element due to surface stresses plus the rate of increase of x, y, and z-momentum due to sources. The Navier-Stokes equations can be simply express as:

$$\partial(\rho u)/\partial t + \nabla \cdot (\rho V u) = \frac{\partial(-p+\tau_{xx})}{\partial x} + \frac{\partial(\tau_{yx})}{\partial y} + \frac{\partial(\tau_{zx})}{\partial z} + S_{Mx}$$

$$\partial(\rho v)/\partial t + \nabla \cdot (\rho V v) = \frac{\partial(\tau_{xy})}{\partial x} + \frac{\partial(-p+\tau_{yy})}{\partial y} + \frac{\partial(\tau_{zy})}{\partial z} + S_{My} \qquad (5)$$

$$\partial(\rho w)/\partial t + \nabla \cdot (\rho V w) = \frac{\partial(\tau_{xz})}{\partial x} + \frac{\partial(\tau_{yz})}{\partial y} + \frac{\partial(-p+\tau_{zz})}{\partial z} + S_{Mz}$$

Where V = ui+ vj +wk , u, v, w are velocity vectors in x, y, and z direction. τ is stress tensor, p is pressure and SM is source terms.

3. Simulation Result of Print Head

Print head can be controlled by the following parameters: frequency, flow velocity and contact angle of the nozzle. In this case, we fixed inlet velocity at -0.3m/s and the actuation force of the piezoelectric. According to piezoelectric effect, the amplitude of the piezoelectric wall is proportional to 90nm in previous simulation. The maximum deformation occurs at the center point of the channel, pushing the droplet out of nozzle when flow across through channel .Giving the different frequency from 2,000 Hz to 20,00Hz which is shown in Figure 3. In the case of frequency

2,000Hz, the droplet is very regular and eject single droplet. The average droplet size is 45μm. In the case of frequency 3,000Hz, the droplet has a long tail with several satellite droplets. In the case of frequency 5,000Hz and 8,000Hz, the condition is much the same as ejecting in 3,000Hz but higher frequency has thinner tail. The droplet size is smaller than previous case. In the case of frequency 10,000Hz and 20,000Hz, the liquid flow back to the chamber and eject very small droplet, special in 20,000Hz, droplet size only 10μm. The phenomenon is like supersonic shake, droplet damping left and right.

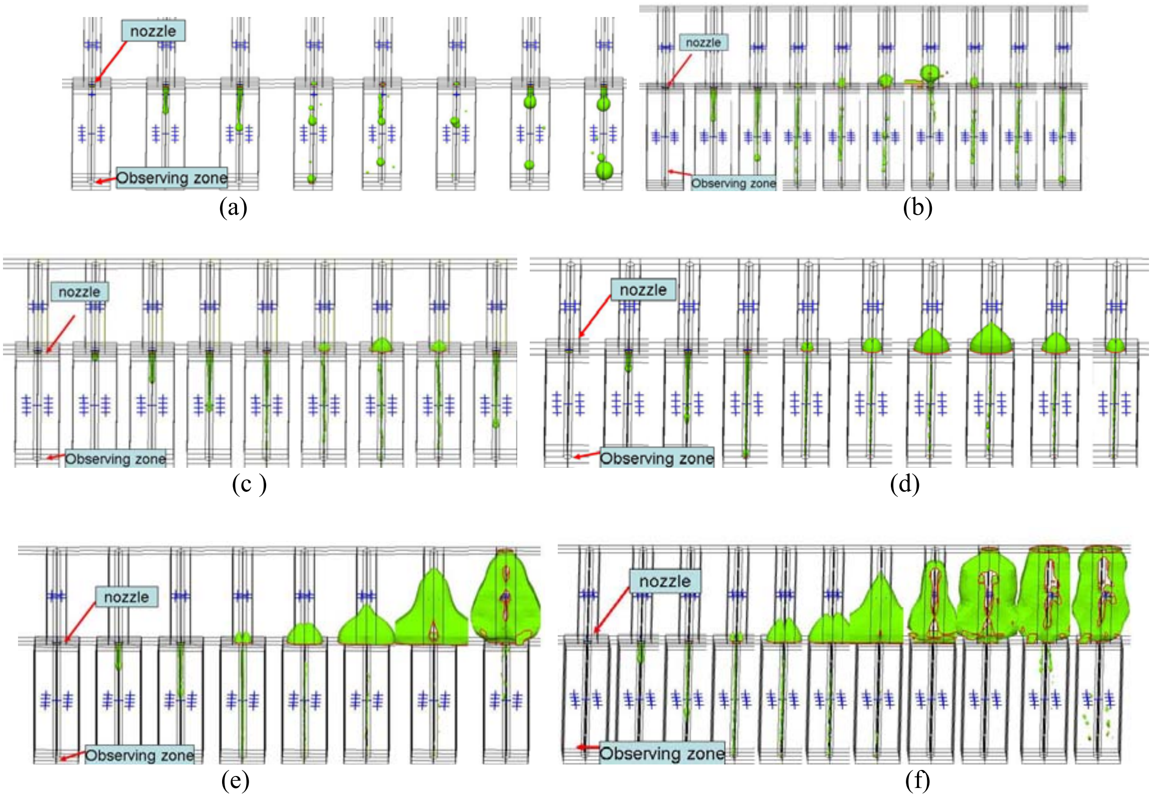


Fig.3. Droplet eject phenomena for case of frequency whish change with the time(a) =2,000HZ (b)= 3,000HZ (c) =5,000HZ (d) =8,000HZ (e) =10,000HZ (f) =20,000HZ

4. Print Head Design and Manufacturing

The authors try to study and design a piezoelectric array printing jet through the state-of-art manufacturing method in micro-electric and machine system (MEMS). Using the piezoelectric plate and cutting channel on it with size 300 μ m, height 360 μ m ,and the diameter of orifice is 32 μ m. The fabricate process is as fig.4. The main body of this print head is use the Sunnytec company piezoelectric chip type S55.To manufacture the actuator wall, clean the piezoelectric chip by acetone a, then dry the chip with the hot plate. As shown in Fig. 5(a).Then the actuator walls and the ink channels is produced by dicing serially using semiconductor wafer cutting machine as shown in Fig. 5(c).

Dicing the size of the micro channel width 300 μ m, height 360 μ m on the piezoelectric chip as shown in Fig. 5(d).Electrodes depositing on shared walls. The amplified view of electrodes dispersion is on the actuator walls. The Fig5(e) is the nozzle with orifice diameter 32 μ m, which is made by Bird Precision Company. To assemble ink channel and electron by using the glue this is made by Locitle campany as shown in Fig.5(f).Last step is that assemble digital camera with microscope to observe ink drop, the experimental setup is shown in fig.5(g)and(h).

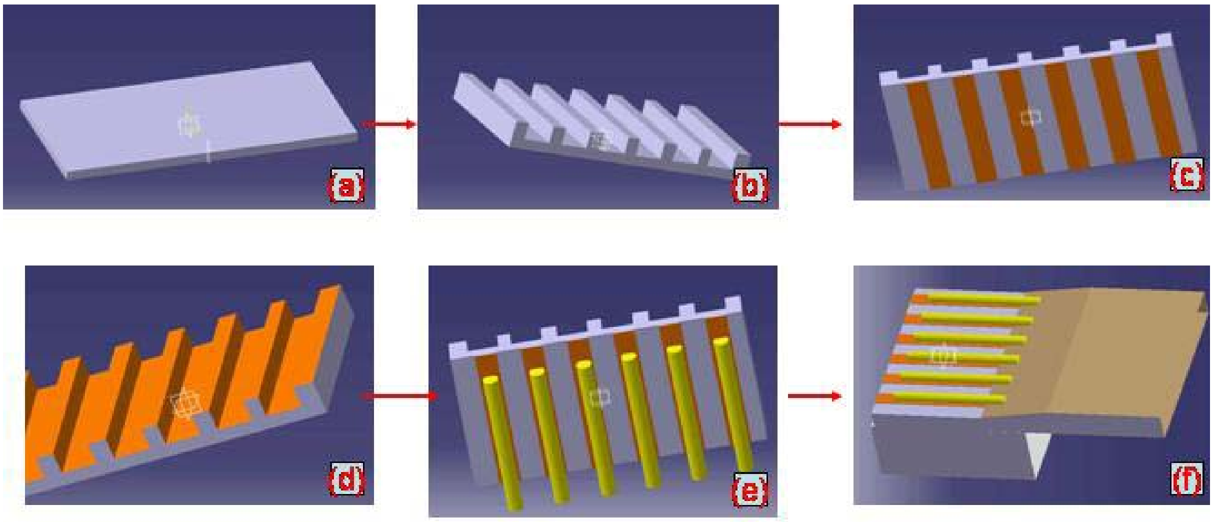


Fig.4. the fabricate process

Fig.5.The print head parts manufacturing

5. Experimental Result of Print Head

The print head devoices into three part, flow chamber, piezoelectric actuator and ejecting nozzle. There is a fixed velocity flow from the inlet to the right side of the chamber; this flow may help print head refill the liquid and also increase ejecting frequency. On the top of channel is piezoelectric actuator which compresses the working fluid to eject from the nozzles. We can vary the ejecting frequency and actuator amplitude by controlling input voltage. If it has enough power to push drop, the last parameter to affect print head is nozzle. The diameter and contact angle of the nozzle; the large size of nozzle's diameter, print head eject easy but also become a jet flow easily. The hydrophilic nozzle (contact angle>90) let the droplet go through the nozzle easily and keep liquid in the chamber before applying amplitude. In the condition, gave voltage is 125 and expect the amplitude of the piezoelectric wall is proportional to 110 nm, inlet velocity at -0.3m/s and the nozzle contact angle is 90 degree. The print head is observed by digital camera with microscope system. The arrowhead point the place of the nozzle and the flow eject is shown in fig 6. In the low frequency eject condition, piezoelectric acuter pushing power is not enough, the drop hung at nozzle without eject. The nozzle eject liquid become the jet when increasing frequency. The jet becomes drop with different droplet size and downstream length in variable frequency. In low frequency condition, the downstream length is much longer than which in high frequency. The average droplet size is 48 μm. The droplet diameter is small in higher ejecting frequency which is about 45 μ m. The print head ejects droplet which is shown in Fig.7, the droplet is regular in frequency 2,000Hz~15,000Hz. When ejecting frequency up to 20,000Hz, The phenomenon is like supersonic shake, droplet become irregular and very small and flow jet damping left and right.

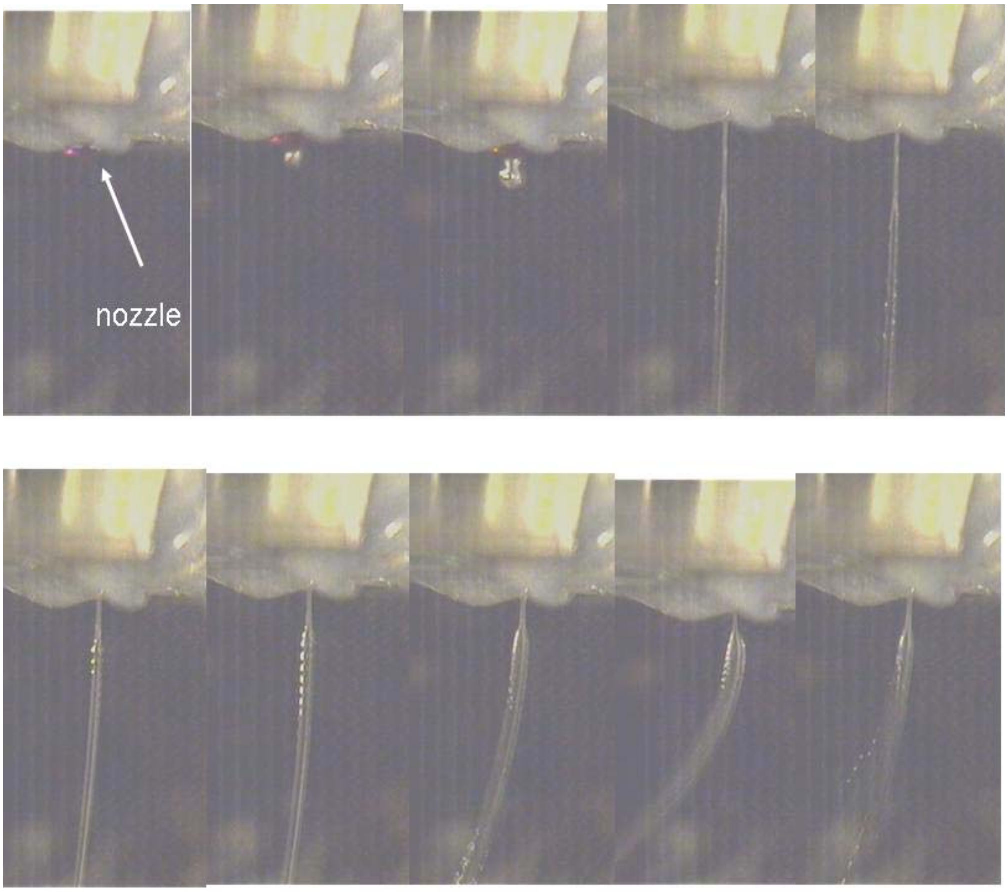


Fig.6. the print head eject drop.

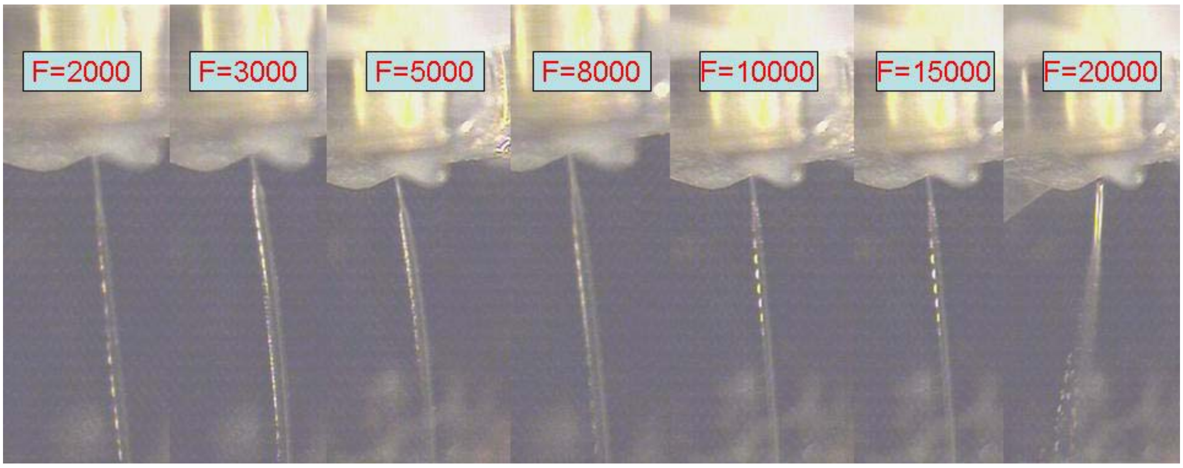


Fig.7. the print head eject in different frequency

6. Conclusions

Simulation

In this case, by fixing the parameter of channel geometry, outlet diameter, just varying the frequency and contact angle. The actuation force of the piezoelectric print head can be controlled by the following parameters: frequency and contact angle of the nozzle. In the condition, the amplitude of the piezoelectric wall is proportional to 65 nm, inlet velocity at -0.3m/s and the nozzle contact angle is 90 degree. The frequency value from 2,000Hz to 20,000Hz, the average droplet size is 45 μm. The droplet size become smaller with the frequency is growth. The frequency and the droplet interval time are corresponding relation. This simulation also shows that when print head operates in high frequency droplet become unstable. The best operation range of the print head is 2,000Hz~8,000Hz.

Experiment

In the condition, the amplitude of the piezoelectric wall is proportional to 110 nm, inlet velocity at -0.3m/s and the nozzle contact angle is 90 degree. The print head let jet become droplet by controlling input frequency. The better operate range is 3,000Hz~10,000Hz, the average droplet size is 48 μm. The droplet diameter is small in higher ejecting frequency which is about 45 μm and the droplet become unstable when frequency over 15,000Hz. The phenomenon of the experiment is corresponding with simulation. The future work is improving this print head and let it become drop-on-demand.

7. References

[1] Y. Endo, S. Sato, T. Saito, S. Nakagiri, Ohno, and Canon Inc., U.S. Patent 4,740,796, Apr. (1988).

[2] B. Keefe, J. M. Ho, F., K. J. Courian, S. W. Steinfield, W. D. Chiders, E. R. Tappon, K. E. Trucba, T. I. Chapman, W. R. Knight, J. G. Mortz, and Hewlett-Packard Company, U. S. Patent 5,648,805, Oct. 6, (1994).

[3] D. J. Hayes and M. W. Hartnett, "*Method for Preparing a Chip Scale Package and Product Produced by the Method,*" U.S. Patent 6,114,187, September 05, (2000).

[4] B. Jayesh, and Y. Yang, "*Polymer electroluminescent devices processed by inkjet printing*," App. Phys. Lett., Vol. 72, No.21, 25 May, (1998).

[5] M. Grove, D. Hayes, R. Cox and D. Wallace, Proc. Display Works'99, San Jose, February (1999).

[6] T. Stephen, "*High Density Multi-Channel Array, Electrically Pulsed Droplet Deposition Apparatus*," U.S. patent no. 5,016,028, (1991).

[7] Y. J. Wu, W. H. Lai, and S. W. Huang, "*Simulation and experiment on the shear mode piezoelectric ceramic print head,*" ICLASS, Japan, August (2006).