Lifetime and Failure Mode Study on the Micro-heater of Thermal Bubble Inkjet

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Abstract

Lifetime and failure mode of the micro heater within thermal bubble inkjet is investigated in this study. Operational lifetime is defined as the firing times for electric pulse signal continuously supplied to micro-heaters until thermal bubble failed to generate on heater surface. Input pulse signal and thickness of the thin-film within micro-heater are two of the most important factors, which may affect the inkjet operational lifetime. In the study of input pulse signal, operational lifetime is significantly affected by the power density, which is defined as the heating power divided by the micro heater surface area. The measurement tricks also cause the significant difference in heater lifetime measurement. Heater lifetime of close-pool trick is about one order higher than that of open-pool trick, which is caused by the extra collapsing force on the thermal bubble. In addition, the failure mode of micro-heater is also observed by using optical microscopy in this study. Phenomena of crater cracks, broad swell and black points on the heater surface are observed which caused the failure mode of micro-heaters. It is noted that the operational lifetime is not obviously influenced by different thin film thickness, which includes layers of TaAl, SiC and Si_3N_4, design within 1.3 micrometer in this study.

Introduction

Improving of the operational lifetime of inkjet printhead leads to cost down significantly especially for the printing process of industrial applications. There are plenty of factors that affect the operational lifetime of micro heater such as ink properties, operating pulse signal, thin film material and structure, etc. Chen et al. (1997) studied on the parameter of beginning voltage input needed for the thermal bubble generated on the micro heater surface. They revealed that the beginning voltage could be related to the time period of heating pulse width. With increasing of the heating pulse width, it is obviously that operational beginning voltage rapidly decreases for the generation of thermal bubble. The empirical formula is obtained and suggested as following

$$V_b = A \times P_w^{-B} \tag{1}$$

where V_b is the beginning voltage of bubble generated on micro-heater, P_w is heating pulse width, and A and B are two constant coefficients. From the viewpoint of heat transfer, superheating and rapid phase changes of the working fluid for generating thermal bubble make its application of ejecting droplet. Inkjet printhead with micro heater array is widely used for home and office applications. Recently, there are deeply potential in industrial applications of inkjet printing technology, such as the manufacture of PLED display, PCB and biomedical engineering, etc. Because of the thermal conductivity coefficients for Ta (57) > SiC (33.5) >> Si_3N_4 (1.67), it is obviously that the beginning voltage are mainly affected by the thickness of SiC and Si_3N_4 film layers. With the increasing the thickness of SiC and Si_3N_4 layer, beginning voltage must be increased, while it also caused the exceeding heat accumulates within them. It may also result in the decreasing of lifetime on micro heaters. It is difficult to decrease film thickness for fabricating process because it may cause the pinholes effects. Besides, the protecting layer of Ta thin film can protect the micro heater surface from the bubble cavitation force's damage.

In this paper, the firing lifetime of the micro heater will be experimentally investigated by the variation of input operating signals and thin film thickness. The growing and collapsing processes of thermal bubble were observed by the CCD optical strobe system and circuit resistance is recorded by hand-made auto measured machine. Optical microscopy is also used to observe the surface profile of the micro heater after operational failure of testing.

Sample Design

Micro heater within the chip of inkjet printer head is fabricated using MENS technique and schematic of the thin film structure is shown in Fig. 1. Thermal insulation layer of SiO_2 material is first grown on the silicon wafer. The heater layer of TaAl is deposited on the SiO_2 layer for the second step and the Al film is applied as the conducting metal electrode. The sheet resistance of TaAl heater film is about 29 Ω. Another two layers of SiC and Si_3N_4 film are deposited on the heater layer (TaAl) and the Ta film deposited on the SiC and Si_3N_4 film as a protecting layer to reduce the impacting force of bubbles on the heater surface.

Two of the important issues are investigated in this paper. First one is the lifetime study with different operating signal on the same thin film structure condition. The other one is the lifetime with different thin film thickness design. They are summarized in Table 1 and Table 2. The heater area size is 45 μm × 45 μm and the overall heater circuit resistance is 33 Ω.

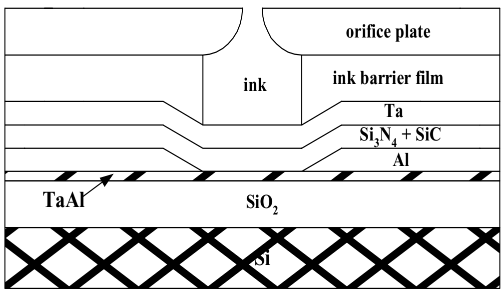

Figure 1. Thin film structure

Table 1. Operating Condition of the Same Input Pulse Width

Test Condition	*Operating Condition*	
	Pulse Width (μm)	*Pulse Voltage (μm)*
1	*8.6*	*2.4*
2	*9.6*	*2.4*
3	*10*	*2.4*
4	*10.5*	*2.4*
5	*11*	*2.4*
6	*11.5*	*2.4*
7	*12*	*2.4*
8	*12.5*	*2.4*
9	*13*	*2.4*
10	*13.5*	*2.4*
11	*14*	*2.4*
12	*14.5*	*2.4*
13	*15*	*2.4*

Table 2. Thin Film Thickness Structure

Style	*Film Thickness (Å)*		
	Ta	*SiC*	*Si_3N_4*
Type1	*2500*	*1250*	*5000*
Type2	*5000*	*2500*	*5000*
Type3	*5000*	*2500*	*2500*
Type4	*2500*	*2500*	*5000*

Experimental Equipment

The equipments setup in this study consist of CCD camera, signal control board that generates different frequency, heating pulse width and the voltage wave functions, the circuit of auto-measuring resistance and PC as shown in Fig. 2 of the schematic.

Figure 3 shows the image captured by optical microscopy and the electrical resistance profile with inject number is shown in Fig. 4.

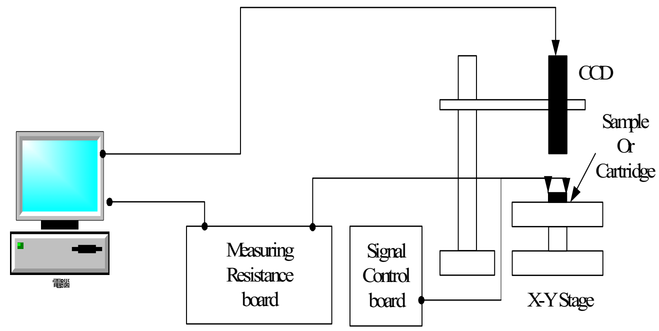

Figure 2. Schematic of equipment

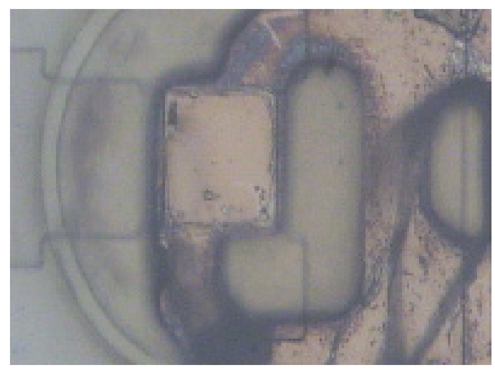

Figure 3. Observed image of different operating signal by optical microscopy

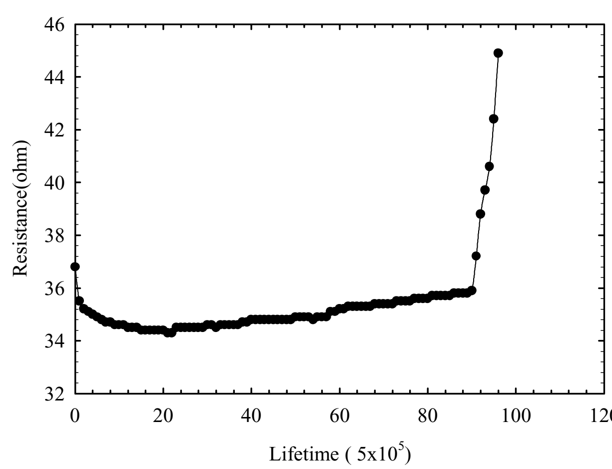

Figure 4. Circuit resistance profile with inject number increasing

Results and Discussion

The experimental results of different operating signal are presented in Figs. 5 and 6. Figure 6 is another form of the result of Fig. 5 according to the relationship given by

$$E = \frac{V^2}{R} \times Pw \tag{2}$$

where E is the operating energy input, R is the circuit resistance; V is the operating voltage and P_w is the operating heating pulse width. Figs 5.and 6 show that the results of different types of input signal profile, which could be divided into three different ranges for injection lifetime. The first range of electrical voltage input is less than 10 volts, the second range is between 10 and 13.5 volts and third range of voltage input larger than 13.5 volts. Results within the first range shows that injection lifetime decreases rapidly with the increasing of voltage results from no bubble generating. The second range shows that injection lifetime decreases tardily and the rapid decreasing lifetime results from overloading current on the heater. Figure 7 shows the images after the operating failure of the micro heater with different operating signal observed by optical microscopy system. It is observed that no cracking points founded on the micro heater surface with 9.6 volts of operating voltage signal after the operational failure of testing inkjet head. With increasing the operating voltage input, the area of cracking point on the micro heater become larger. Cracking point on the micro heater surface is in convex profile and the image shows a crater for voltage input within the range between 10.5 and 11.5 volts and a broad area of island raised with voltage input over 11 volts. The reasons for the difference could be the extra bubble collapsing force on the micro heater surface and overheating of the micro heater which leads to the gas may released from the thin film structure of Si_3N_4 or SiC layers when the temperature rapidly increasing.

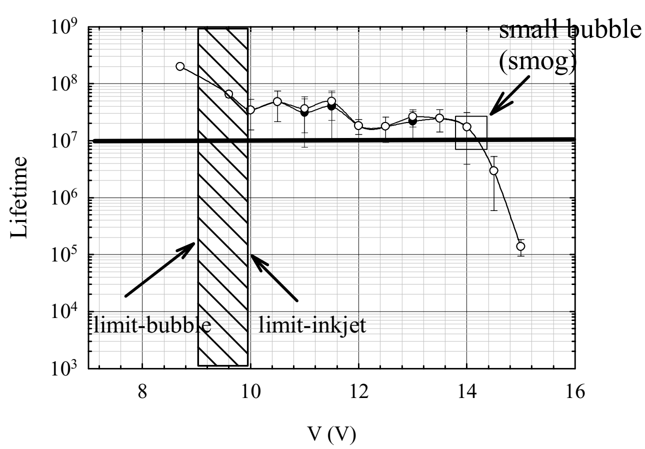

Figure 5. Lifetime profile of pulse width 2.4 μsec, ,frequency 5KHz with the increasing of pulse voltage for open-pool trick

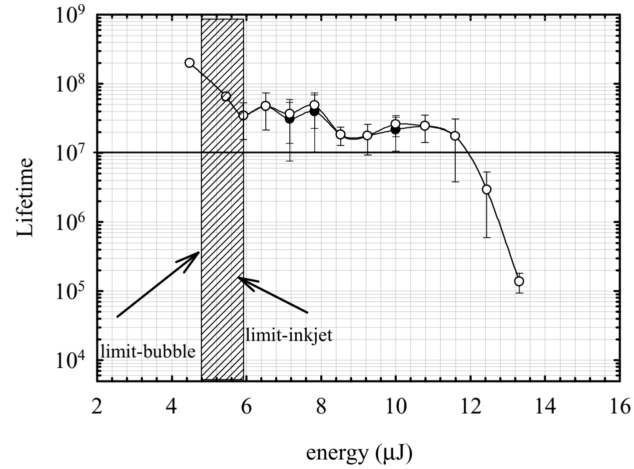

Figure 6. Lifetime profile of pulse width 2.4 μsec with the increasing of energy open- pool trick

Figure 8 shows the result that close-pool trick will affect the injection lifetime on the micro heater, but open-pool trick seems not. For close-pool trick, the injection lifetime decreases with the increasing of frequency. This reasons maybe result from refilling good enough in high frequency. In addition, heater lifetime of close-pool trick is about one order higher than that of open-pool trick. The reason maybe result form the difference of bubble collapsing force. For open-pool trick, the extra collapsing force on the micro heater is generated because of being covered with the work fluid anytime. But close-pool trick has no the extra upright collapsing force because the work fluid vanishes after injecting. Figure 9 shows the schematic of the bubble collapsing profile on the micro heater.

Relationship between the structure of thin film thickness and heater lifetime is also investigated in this study. The experiment samples are summarized in Table 2 and the experiment result for the beginning voltage is given in Table 3. This shows that it is obvious that the beginning voltage rises with increasing of the SiC and Si_3N_4 film thickness. In order to compare with the heater lifetime difference of four types, the operating voltage of open-pool trick is 1.22 times than the beginning voltage according to the empirical experience of experimental testing. Figure 10 is the experimental result of Table 3 with open-pool trick. The result shows no difference of heater lifetime for all the four types of testing condition, which leads to the conclusion that operational lifetime may not be affected by different of thin film thickness design obviously. However, it is important to note that if the film thickness was not thick enough, the failure mode of micro heaters may transferred to another kind of mechanism. Figure 11 shows that the circuit short with Type 1 testing condition in open-pool trick. This failure may be caused by the pinholes that deposited on SiC and Si_3N_4 films and leakage current makes the electrical circuit short.

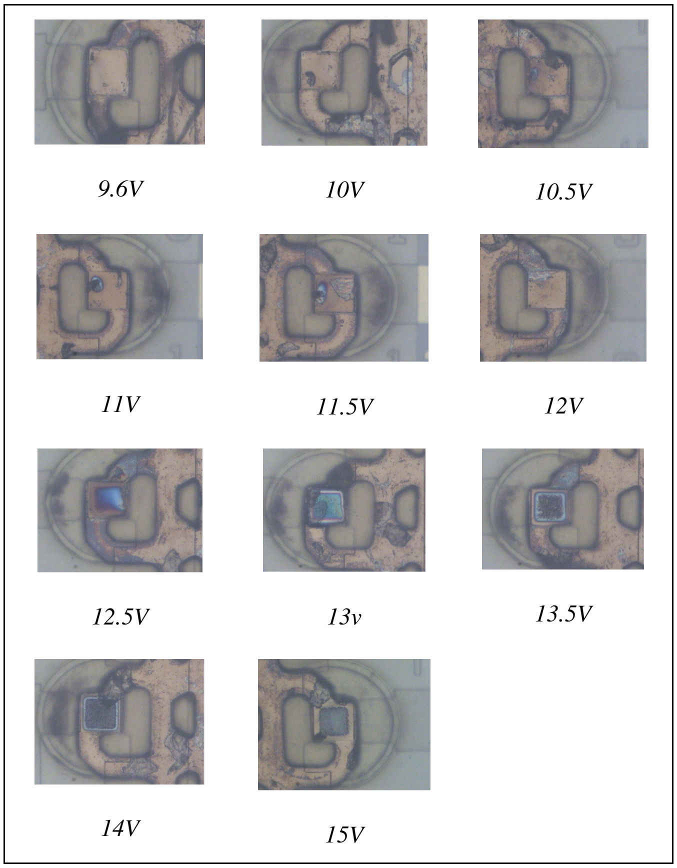

Figure 7. Failure image of observed by optical microscopy

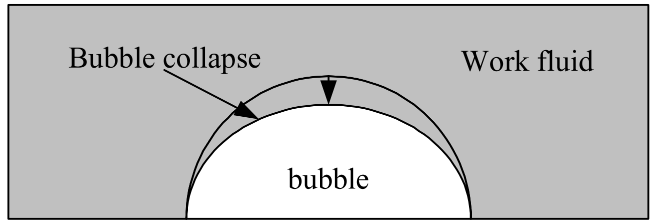

Figure 9. Bubble collapsing profile

Table 3. The Beginning Voltage of Different Thin Film Thickness Sample

	Beginning Voltage (V Pulse Width (μsec))		***Operating Condition***	
	Average (V)	***Standard Deviation (V)***	***Pulse Width (μsec)***	***Voltage (V)***
Type1	*8.64*	*0.19*	*2.4*	*10.5*
Type2	*8.9*	*0.17*	*2.4*	*10.8*
Type3	*9.8*	*0.08*	*2.4*	*11.9*
Type4	*9.42*	*0.06*	*2.4*	*11.5*

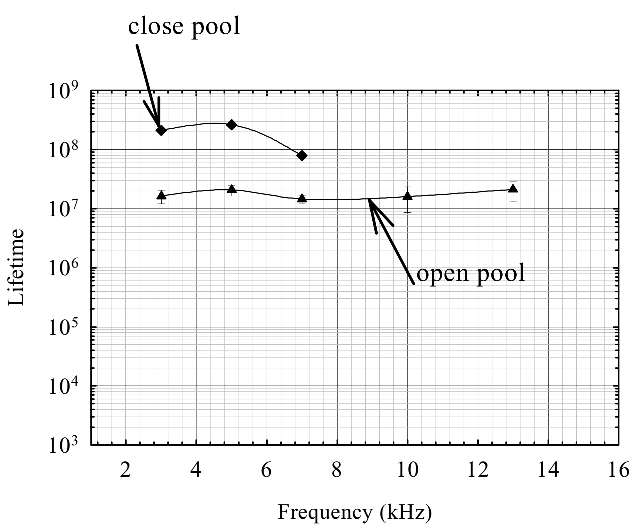

Figure 8. Lifetime profile of pulse width 2.4 μsec, operating voltage 12.5V, with the increasing of firing frequency

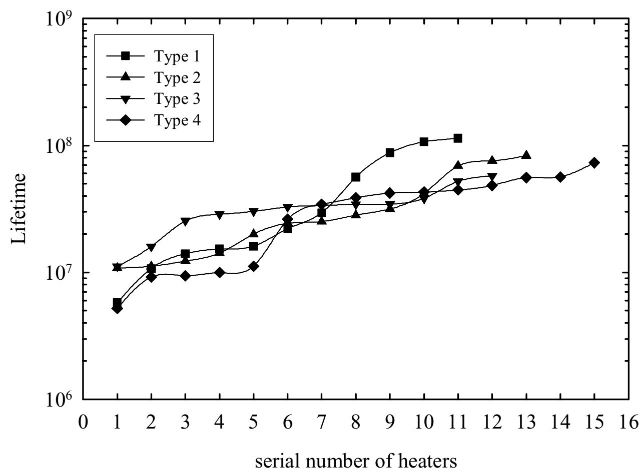

Figure 10. Lifetime profile of Table 3 open-pool trick

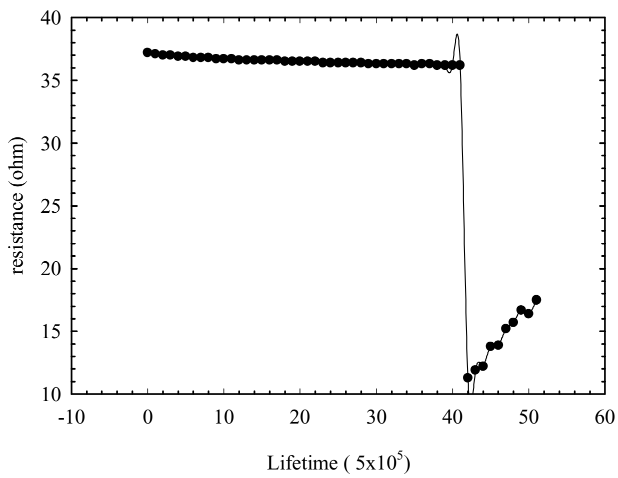

Figure 11. Resistance profile of Type 1 for open-pool trick

Summary

Micro heaters of thermal bubble inkjet printhead are investigated to study the operational lifetime with different signal input and thin film thickness structure design for both open-pool and closed-pool tricks. From the viewpoint of heat transfer mechanism, different of film thickness result in the different of beginning voltage needed for generating thermal bubble. However, the operational lifetime seems not to be influenced significantly by different of thin film thickness design. It is noticed that pinholes may cause the leakage of electrical current and result in circuit short as the thin film thickness decreasing. Operating lifetime of micro heater with close-pool trick is about one order higher than that with open-pool trick, which is caused by the extra collapsing force on the thermal bubble and heater surface.

References

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Biographies

Ming-Hong Chuang received his M.S. degree from National Chiao-Tung University Institute and Department of Electrophysics in Taiwan. He joined the Printing Technology Division of OES/ITRI in 2001. His interest lies in optical-electrical semiconductor.

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