Analysis of Bubble Pressure Bubble Jet Printing Technology

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Introduction

The pressure of a vapor bubble generated in ink determines volume and velocity of ink droplets expelled from a nozzle. The pressure also damages the heater surface where the bubble nucleates and collapses. The precise knowledge of bubble dynamics including bubble pressure will be, therefore, helpful to improve printing quality and a heater lifetime of the bubble jet printer. Measurement of acoustic emission (AE) wave generated by a vapor bubble is an effective method to study bubble dynamics.

Meyer[1] has shown properties of detected AE signals from vapor bubbles in several kinds of liquids. Sakurai *et al.*[2] have proposed acoustic source wave analysis of detected AE signal from a vapor bubble in a liquid. The source wave was, however, not quantitatively obtained by their method.

In this paper, we present a new method to measure force acting on the bubble jet heater board quantitatively while a vapor bubble nucleates, grows and collapses. We also discuss bubble growth dynamics.

Experimental

The measurement system is shown in Figure 1. A platinum thin film heater (100 μm × 400 μm) made on a heater board (l8*mm* × 12*mm*) superheats liquid. The heater board is adhered to a silicon substrate. A glass cell is installed on the heater board and filled with liquid. No nozzle is formed around the heater so that a vapor bubble can nucleate, grow and collapse freely in the liquid. An AE sensor is adhered to the silicon substrate in a distance of 25*mm* from the heater. The AE sensor has a frequency range of 4MHz and a non-resonating structure. AE wave generated by a vapor bubble on the heater board propagates in the silicon substrate and is detected by the AE sensor.

The force $f(t)$ acting on the heater board is given by

$$f(t) = \int_0^t v(\tau) g^{-1}(t-\tau) d\tau, \quad (1)$$

where $v(t)$ is detected AE signal and $g^{-1}(t)$ is the inverse function of a transfer function $g(t)$ from an AE source to an AE detector[3,4]. To calculate $f(t)$, we must know the transfer function $g(t)$. The function $g(t)$ can be experimentally determined using an artificially generated AE wave.

We have obtained the function $g(t)$ by dropping a steel ball on the heater board. The force acting between the steel ball and the heater board in contact can be calculated theoretically[5]. The calculated force is impulsive with acting duration of about 3μs. The force by the steel ball is similar to the force generated by the bubble pressure in nucleation or in collapse. In addition, the steel ball can input the AE wave into the heater board at the same location where the vapor bubble inputs the AE wave. Therefore, the transfer function $g(t)$ can be obtained precisely by the steel ball experiment and finally the force $f(t)$ can be obtained precisely.

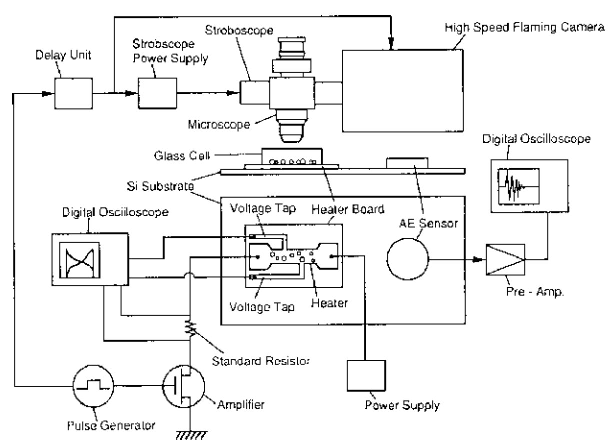

Figure 1. Measurement System

Results and Discussion

Force Acting on the Heater Board

Figure 2 shows the force acting on the heater board while a water vapor bubble was generated in superheated water. The first force peak appears around 1μs and corresponds to the photograph of the bubble in film state at 1μs shown in Figure 3. The peak value is 0.58N. The second peak appears around 20μs and corresponds to the photograph of the bubble collapse at 20μs shown in Figure 3. The peak value is 0.70N. The peak A, the largest peak after the second peak, corresponds to the photograph of the bubble collapse at 28μs shown in Figure 3.

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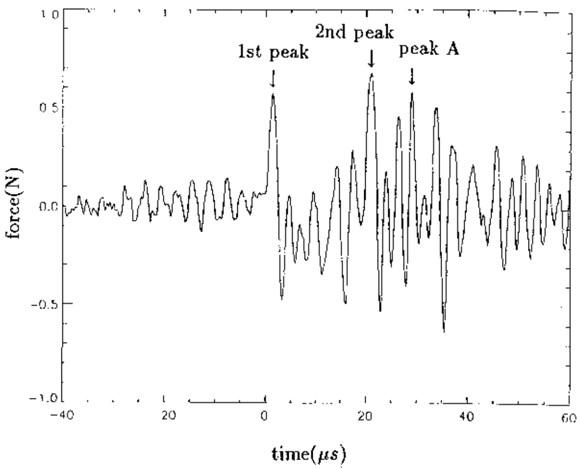

Figure 2. Force Acting on the Heater Board

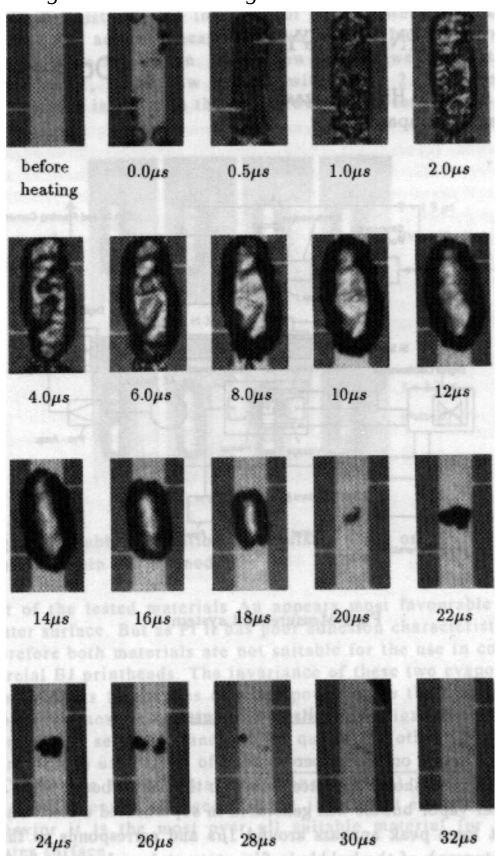

Figure 3. Photographs of a vapor bubble generated in superheated water. Number below each photograph indicates time from the start of nucleation. Small bubbles nucleated on the heater from 0.0μs to 0.5μs and combined into a bubble in film state around 1μs. The bubble continued to grow until around 8μs, started to shrink and collapsed around 20μs. Then the bubble rebounded or reappeared and collapsed around 28μs. The photographs were taken by a high speed flaming camera 'Ultranac'. Exposure time was 0.45μs.

Bubble Nucleation Pressure

The bubble nucleation pressure can be obtained dividing the value of the first force peak by the area where the force acts on. The area is, however, difficult to determine precisely, because the force acts on the heater board not only from the bubble, but also from the liquid pressured by the bubble. The value of the first force peak is 0.58*N* in Figure 2 and the heater area is 40000μm^2. Therefore, the bubble nucleation force divided by the heater area is 14.5 MPa. The saturated vapor pressure of water is 8.6MPa at 300°C which is near the bubble nucleation temperature 302°C obtained by measuring the heater resistance[6]. The difference between the calculated pressure and the saturated vapor pressure is reasonable, because the area where the force acts on actually is estimated to be larger than the heater area. This shows that the force caused by the bubble pressure can be measured quantitatively by our method.

Bubble Growth Dynamics

The force in Figure 2 turns negative around 2μ*s*. The negative force means that the bubble pressure is lower than the atmospheric pressure. The observed bubble continues to grow until around 8μ*s* and then starts to shrink as shown in Figure 3. The bubble, therefore, continues to grow under the lower inside pressure than the atmospheric pressure. This shows that the bubble grows because of the ink inertia after nucleation.

Bubble Collapse Pressure

The force in bubble collapse is nearly equal to the force in nucleation in Figure 2. The bubble in collapse is much smaller than the bubble in nucleation as shown in figure 3. Therefore, the bubble collapse pressure is much higher than the bubble nucleation pressure. The high pressure in bubble collapse may damage the heater surface.

Conclusions

1. We have developed a new method to measure force acting on a bubble jet heater board quantitatively while a vapor bubble nucleates, grows and collapses.
2. The vapor bubble continues to grow after nucleation under the lower inside pressure than the atmospheric pressure.
3. The bubble collapse pressure is much higher than the bubble nucleation pressure.

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