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Pulse and Temperature Control of Thermal Ink Jet Printheads Without a Heater Passivation Layer

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Abstract. *One of the ways to improve the heating efficiency of a heater is to eliminate the passivation layer of the heater by using TaSiO for the heater material, whereby the heater surface becomes thermally oxidized. Rapid boiling of water occurs at around 300°C; therefore, it is necessary for the fabrication condition of the oxidation layer to correspond to a temperature higher than the boiling temperature. In a pulse drive during printing, it is also necessary to keep the heat at a temperature lower than that of thermal oxidization to prevent deterioration. As a result of observing the generation of bubbles and measuring the heater temperature, it was confirmed that within the range of heating velocity in this experiment, boiling starts at around 300°C, and it was also possible to understand pulse control in thermal ink jet printheads to maintain the heater at an appropriate temperature. © 2008 Society for Imaging Science and Technology.*
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INTRODUCTION

One effective method for achieving higher speed in thermal ink jet (TIJ) printers is to increase the nozzle count. As an increase in nozzle count triggers an increase in the amount of input energy, it is desired to increase the thermal efficiency of each heater, and accordingly to reduce the amount of energy that is required by the printer as a whole. One measure to improve heat generation efficiency of each individual heater is to decrease the thickness of the passivation layer of the heater, which is correlated to heat capacity during heat generation. Figure 1 shows the measurement results for the change in energy required for producing droplets, depending on the thickness of the Ta passivation layer in a conventional printhead. Out of the total heat flux generated from a heater having a Ta passivation layer 0.5 μm thick, only 25% of the heat flux was transferred to the liquid side and contributed to boiling.[1]

Studies on eliminating the passivation layer of a heater have been carried out. As a feasible method, a structure that uses TaSiO as the heater material has been proposed by Mitani et al.[2,3] By thermal oxidation of the heater surface that comes in contact with ink beforehand to form a self-limiting film with thickness ~0.01 μm that protects against chemical attacks from ink, an improvement in heat efficiency becomes possible. In this method without a passivation layer, there are concerns regarding physical attacks on the heater surface that occur during the collapse of bubbles, i.e., cavitation damage, but this problem can be avoided by using the so-called air communication method.[4,5]

Fundamentally, however, it is desirable for the TaSiO film to have sufficient strength for resistance against cavitation damage. The reason for this is that the size of bubbles changes with time, and an air communication state is not maintained at all times. Furthermore, when the size of bubbles is reduced due to kogation, a technology for applying intentionally low energy that allows for the generation of small bubbles[6] is not suitable as a solution.

It has been made clear by Iida, Okuyama et al. that based on photographic observations, the phenomenon of transient boiling of water, which is the principle of operation of TIJ heads, occurs at around 300°C.[7–9]

On the other hand, the fabrication temperature of a heat oxidation layer on the heater surface is approximately 400°C, taking the boiling temperature of water and the nature of the material into consideration.[2,3] This may cause deterioration of the heater when the temperature exceeds 400°C, which leads to changes in the heat generation con-

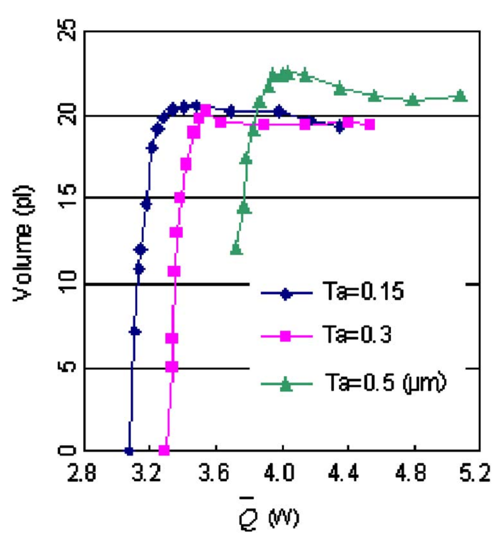

Figure 1. Effect of Ta thickness to drop generation.

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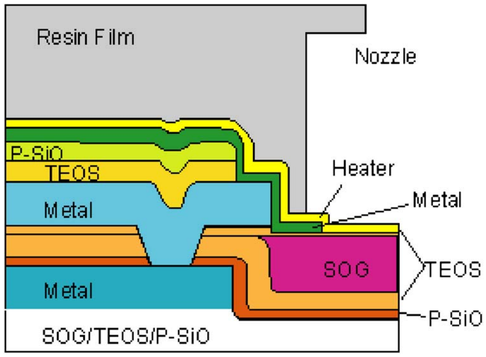


Figure 2. Schematic diagram of printhead structure (cross section).

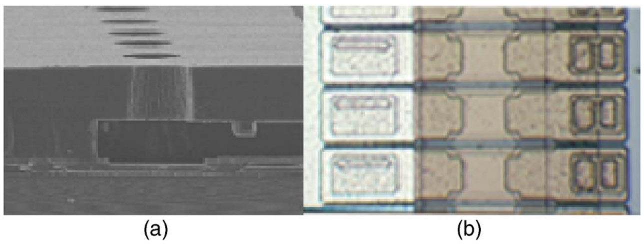


Figure 3. Print head structure (a), nozzle cross section (b) birds-eye view of heater surface.

ditions, which in turn causes changes in the generation of bubbles, resulting in changes in the drop ejection conditions of the jet and a lower print image quality. Accordingly, it is important for the pulse drive of a heater system without a passivation layer to provide the heater with stable and sufficient energy for bubble generation, as well as to provide the minimum energy required to stabilize the heater material and to lower the energy of the entire system.

In this article, observations on the conditions for bubble generation and measurement of the heater temperature were carried out for TIJ printheads that use a heater without a passivation layer, and, together with planning for the optimization of the drive pulse, studies on the behavior of bubbles were conducted.

HEATER STRUCTURE AND HEAT EFFICIENCY ENHANCEMENT IN THIS METHOD

A schematic diagram of a printhead structure that realizes a heater without a passivation layer by using a thin film process for semiconductors is shown in Figure 2. Figure 3(a) shows a scanning electron micrograph of the cross section of the printhead, including the nozzle, and Fig. 3(b) shows an optical microphotograph of the heater surface.

Here, the thickness of the TaSiO heater material is 1000 Å. Two types of heater structures were prepared, one designed with a heat generation area of 23×23 μm^2 and another with a heat generation area of 30×30 μm^2.

In addition, for the structure of a conventional heater to be used for comparison, a heater device using TaN as the heater material, Ta for the heater passivation layer (thickness of 2000 Å), and SiN for the heater insulating layer (thickness of 2000 Å) was prepared.

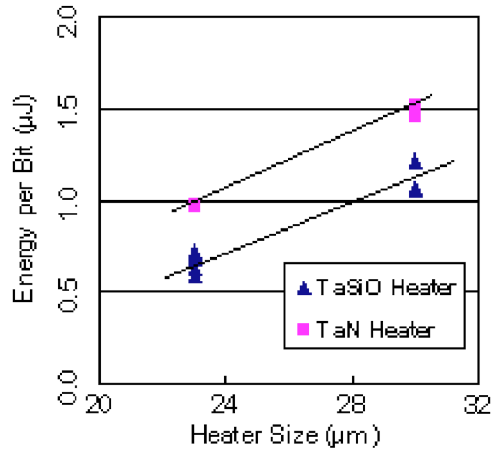


Figure 4. Measured ejection energy.

A pulse wave with a width of 1.0 μs was applied to each heater in water, and the bubbles generated on the heater were observed while changing the pulse power. The behavior of bubbles was observed by a stroboscopic microscope with a lighting-emitting diode (LED) light source that emits light in synchronization with the drive pulse of the heater. The light emission time was approximately 0.1 μs; when the reproducibility of the phenomenon is higher, its observation is more stable.

Together with an increase of pulse power applied to the heaters, bubbles are generated initially from only a part of the heater surface, and this area with bubbles grows gradually. However, the size of the bubbles becomes saturated and does not change after awhile. This saturation point, based on past observations of ejection states where an ink jet head with nozzles was used, is defined as an ejection energy in this study, and the energy being consumed by the heater is assumed to be the energy required for ejection. Figure 4 shows the results of measurements for ejection energy per bit, depending on the type and area of the heater. This figure shows that compared to the conventional TaN heater that has a passivation layer, the TaSiO heater without a passivation layer can eject drops with approximately 70% of the energy used for the TaN heater.

STUDY ON INCREASE IN HEATER TEMPERATURE

Device for Evaluation

For the purpose of measuring the heater temperature, a heater device equipped with measurement terminals on both ends of the TaSiO was made. To obtain varying resistances, temporal changes in the current flowing through the heater were measured.[7–9] This device, as shown in Figure 5, is equipped with a total of six terminals, including address and common terminals for power supply, and Va, Vc, Va_s, Vc_s terminals for measuring the voltage. The difference between the Va and Va_s terminals, and between the Vc and Vc_s terminals depends on the exit position of the applied current, namely whether it is located in the center of the heater edge or on the outside of the edge. The dotted region in the center represents the heating area, and the electrodes

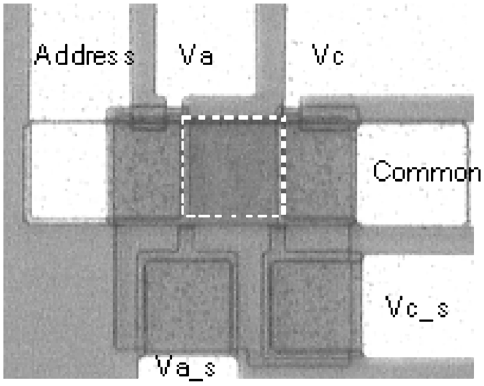


Figure 5. Heater device for temperature measurement (heater dotted area).

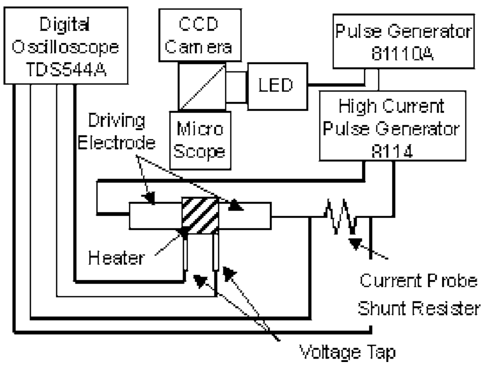


Figure 6. Schematic diagram of measurement system.

(*Va* and *Va_s*) for measurement in the device in Fig. 5 are both wired by a metallic film (TiW) in the intermediate layer between the heater and aluminum electrode.

Evaluation Method

The objective of this evaluation is to measure changes in resistance of the heater in a driving state in real time. The schematic diagram of a measurement system is shown in Figure 6 and the measurement procedure is as follows.

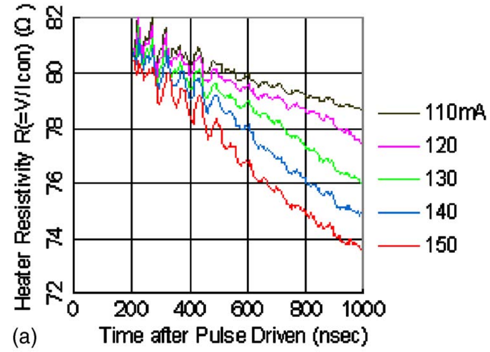
(1) A constant current pulse is applied to the heater using a high current pulse generator.

(2) At this time, the voltage at the terminals for voltage measurement that are located at both ends of the heater is measured with a digital oscilloscope, and the voltage applied between the terminals, i.e., both ends of the heater, is also calculated.

(3) At the same time, the voltage of a shunt resistor that is inserted vertically in the measurement system is measured using a digital oscilloscope, and the value of the current value flowing at the given resistance value to the system is calculated. As the device is operating in a constant current mode, the value of the current is constant even if the resistance value of the heater changes.

(4) Based on the voltage difference and the current value obtained from steps (2) and (3), the change in the resistance value during the time that the pulse was applied is obtained.

(5) Values are converted to temperature using a resistor temperature coefficient.



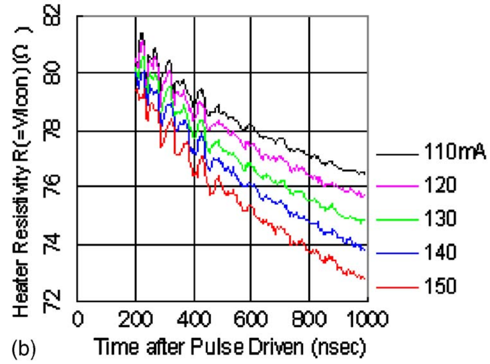


Figure 7. (a) Changes in resistivity of pulse heating with water. (b) Changes in resistivity by pulse heating without water.

Evaluation Results

Measurement of Changes in Heater Resistance Values

Figure 7(a) shows the measured changes in the resistance values. The horizontal axis represents the time elapsed after heating started, and the vertical axis represents resistance. In this graph, data between 0 and 200 ns are omitted because there was a delay of approximately 100 ns in the startup of the waveform after the pulse was applied, and there was also a great deal of noise during this period. Figure 7(a) shows that there is a tendency for the resistance value to decrease as the applied current value increases, which indicates that each heater has a different peak temperature. It is known that in response to the start of boiling, the shape of temperature change curve varies,[8] but in the measurement of this heater, no obvious change was seen. Therefore, the following investigation was conducted.

Figure 7(b) shows the results of measuring the change in resistance values by driving the same heater in air. Subsequently, Figure 8 shows the difference between Figs. 7(a) and 7(b), that is, the difference in the change in resistance values between when the heater is heated in water and in air. In the range from 120 to 150 mA applied current, it is shown that each difference curve has a peak depending on the current value after application of the pulse begins. In other words, because the rise in temperature in water is gradual, although it may be slight in comparison with the temperature rise without water, until the heat conduction is cut off due to boiling, a time-dependent difference in resistance measurements between the heater in water in comparison with in air becomes apparent and is a function of applied current. On

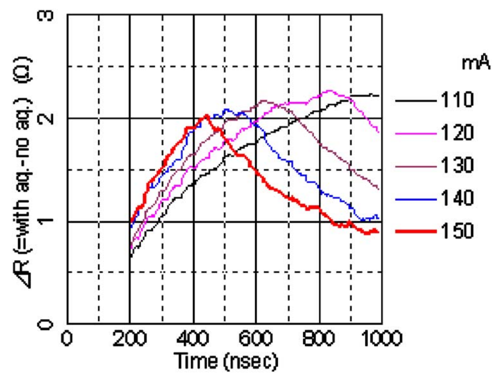


Figure 8. Differences in resistivity by pulse heating.

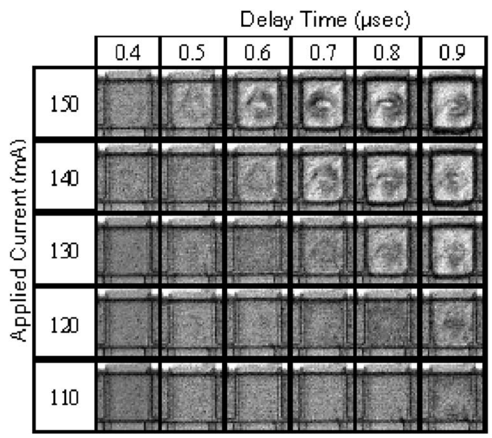


Figure 9. Boiling observations on heater surface

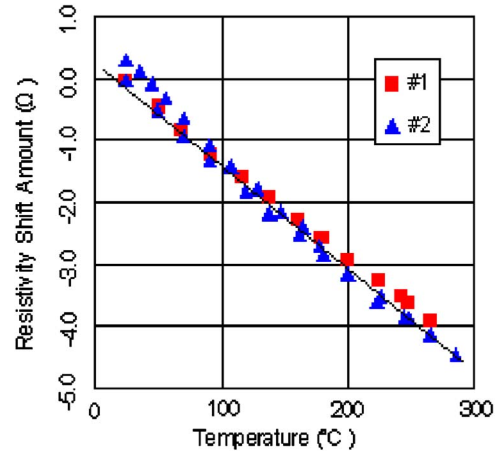


Figure 10. Changes in heater resistivity.

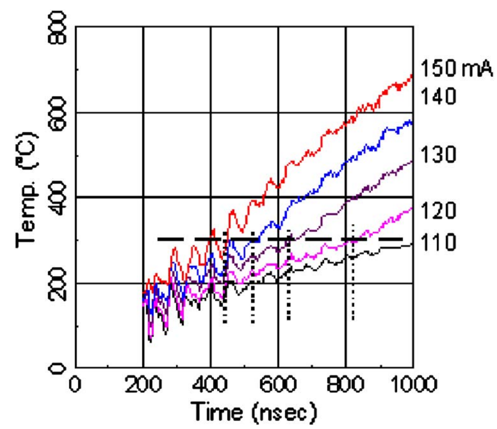


Figure 11. Estimated heater temperature.

the other hand, it is thought that after boiling starts and the heater surface and the water surface are separated, both generate heat in air, resulting in a decrease in the temperature difference, and the point in time when the slope of the line shifts from positive to negative appears to be at around the time when the boiling starts.

Observation of the Boiling Configuration

Figure 9 shows the results of observing the boiling condition for each driving current. A circular projection near the center of the heater surface, which appears to be a bubble, was observed, and at the same time, bubble growth was observed along the whole surface of square heater. However, bubbles were not found when the applied current was 110 mA, which corresponds to the fact that there is no peak for the same conditions in Fig. 8 either. The higher the value of the applied current, the faster bubbles are formed; the inflection point of the resistance curve shown in Fig. 8 occurs at a time just before the circular projection is formed, hence, we infer that the measurement of the heater temperature at this point corresponds to boiling behavior.

Temperature Change of the Heater

Resistance values were measured while changing the head temperature using the four-terminal mode of Multi Meter 3456. At this time, the measurement current that was flowing through the heater was limited to 1 mA, enabling an increase in temperature caused by the measurement current to be ignored. The head temperature was controlled by a hot plate and the temperature was measured using a thermocouple. Measurements were made over the cycle of 25°C $\rightarrow$286°C$\rightarrow$25°C in intervals of approximately 20–25°C. Figure 10 shows the results as a function of heater resistivity, based on the heater resistance when measurements began at room temperature. It was found that resistance decreased with an increase in heater temperature, and that the two samples studied exhibited almost no individual differences.

Figure 11 shows the temperature change for the heater as calculated from Fig. 7, when a heating pulse of 1 μs is applied to this heater, estimated using the temperature characteristics for the heater obtained above. The peaks shown in Fig. 8 were measured at 440, 510, 630, and 820 ns, respectively, after heating started, and when they were plotted as a dotted line in Fig. 11, the temperature of the heater during these peaks was generally found to be near 300°C.

The temperature exceeded 400°C approximately 100 ns after the temperature reached 300°C. Accordingly, when driving this heater, it is preferable to make the input current 120 mA or less in cases where the pulse width is 1 μs. If driving the heater at a higher energy, it is favorable to stop heating the heater immediately after boiling begins. From the standpoint of variations in manufacturing, however, since there may be cases where the heater temperature reaches 400°C for an applied current of 120 mA, this becomes an issue in terms of practical use.

In this experiment, the heating speed for the heater is fast, in excess of 10^8 K/s. Accordingly, boiling behavior is based on spontaneous nucleation, which is theoretically clarified by precise and detailed observation of bubbles in various kinds of liquids by Iida, Okuyama et al.[7–9]

SUMMARY

A structure for a printhead without a passivation layer for a TIJ heater made of TaSiO using a thin film process was realized, and it was confirmed that energy for drop ejection was reduced. Upon measuring the heater current and observing the boiling configuration using this printhead, it was possible to explain that the boiling behavior corresponds to an increase in temperature. In addition, by obtaining the conditions for the pulse drive when using this heater, guidelines for using this heater as printer were also obtained.

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