The Characteristics of Thin Film Heater Having a High Resistance

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Abstract

The necessity of heater having a high resistance is rising for the better printing performance in the inkjet printer. The characteristics of thin film resister layer made of a tantalum-aluminum-oxy-nitride (TaAlON) have been experimentally investigated in the stability and durability. It was able to control the electrical resistivity of TaAlON thin film by changing the gas flow ratio such as Ar, N_2 and O_2 within a certain range of working pressures in sputter. Totally, seven heaters whose resistance range was from 36 to 390 Ω/sq were prepared for selecting the reliable gas composition rate through the electrical and step stress tests. The open pool bubble tests were conducted to check the electrical strength of thin film layer. To see the feasibility as a heater, the ink ejection tests have been performed with a square and split heater. The shape and velocity of ink droplet were monitored during the lifetime tests.

Introduction

According to the continued advance of civilization, various recording devices were invented and developed. The inkjet printer, one of the big breakthroughs, was commercialized in the 1980s and had done much to popularize 'printer' at small offices and home. There are several ways to pump an ink from the inkjet head to the media [1] and the thermal type is currently dominant in the market. The conversion of electrical energy to heat needed to make a vapor bubble in the small chamber of inkjet head is the main function of thin film resister. Due to its importance, lots of studies have been done to develop the novel material which has a stability and durability and there were some accomplishments such as WSiN, TaSiO, TaSiN, or TaAlN [2-5].

The demand for high speed, high photographic-quality, and high resolution increases the interest about the high resistance heater since it has several merits and increases the efficiency of inkjet head. First, it is able to reduces the energy loss occurred at the circuit during the firing. Second, at the multi-nozzles simultaneous firing time, it can increase the energy uniformity applied in each heater. Finally, due to the increase of the width of 'driving margin', it helps to design the proper voltage setting.

In this study, the characteristics of thin film resister, TaAlON heater, has been investigated on the performance as a heater. Step-stress tests (SST) were conducted to check the electrical strength of thin film layer. Through the open pool bubble tests, the bubble behavior on the heater was monitored and the life time of thin film resister was checked. With Square and split shape heaters specially designed for a high resistance heater, the ink ejection tests were conducted and the ejected droplet and its speed was measured.

Thin Film Resistor

Design

The conventional thermal inkjet thin-film techniques were used to fabricate the heater layers shown in Figure 1. The thin film resistor deposited by the reactive magnetron sputtering techniques. The heater layers consist of a thermal barrier layer, thin film resistor layer, electrodes, passivation layer and anti-cavitations layer. Heat energy transduced from electrical energy applied to heater resistor contributes to actuating bubbles in inks.

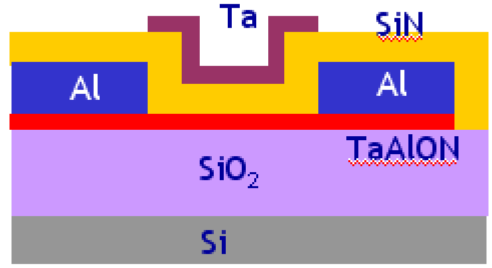
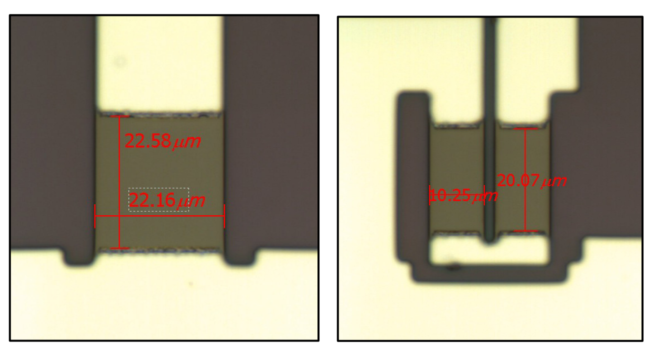


Figure. 1 Schematic of heater layer in an inkjet head

Fabrication process

The tantalum-aluminum-oxy-nitride (TaAlON) was deposited onto thermally oxidized Si substrate by sputtering [6]. Silicon nitride (SiN_x) and tantalum (Ta) was deposited as a passivation and anti-cavitations layer, respectively.



(a) Square heater (b) Split heater

Figure. 2 Photograph of the square and split heater.

The 99.99% purity of Ta-Al alloy target alloyed by 50:50 atomic percent were mounted on two 4-inch diameter sputtering cathodes. The electrical resistivity of thin film layer was able to differentiate by varying the gas flow rate such as Ar, N_2 and O_2. The proportion between N_2 and O_2 was varied 0.1:1 to 10:1 and the proportion of Ar to N_2+O_2 was also varied 1:0.1 to 1:0.4. To change conditions, sputter power was applied 1000~1500W and the process pressure in the chamber were also controlled 4~6mTorr.

Depending on the sputtering conditions, it can be possible to set the resistance of thin film heater. The thin film resistance was 1000~1500 μΩ·㎝. The square shape of heater shown in Figure 2 (a) was used to investigate the resistance at the given conditions. To get the high resistance heater, the split shape heater connected the square shape in series was designed as shown in Figure 2 (b).

Experimental Results

Composition rates of thin film layer

The thickness and resistivity of TaAlON thin film were measured by VSEM and four-point probe. Composition rates of Ta, Al, O and N was analyzed by X-ray photoelectron spectroscopy (XPS) with Al K_α radiation. The composition of evaporated thin film heater was analyzed using XPS. The analysis condition is as following;

(1) X-ray: mono Al k 1486.6 eV, 100 um
(2) Take off angle=45o
(3) Reference: C 1s=285 eV
(4) Timed sputter: 1keV, 7min, 2x2

Table. 1 Thin film heater (TaAlON) composition rate

Area Comment	Ta	Al	O	N
TaAlON	35~45	15~20	15~16	20~25

Table 1 shows the thin film heater's composition ratio. Ta, Al, O and N were 35~45, 15~20, 15~16, and 20~25at%, respectively. XPS spectrum described the energy level of each component in thin film resister is shown in Figure 3.

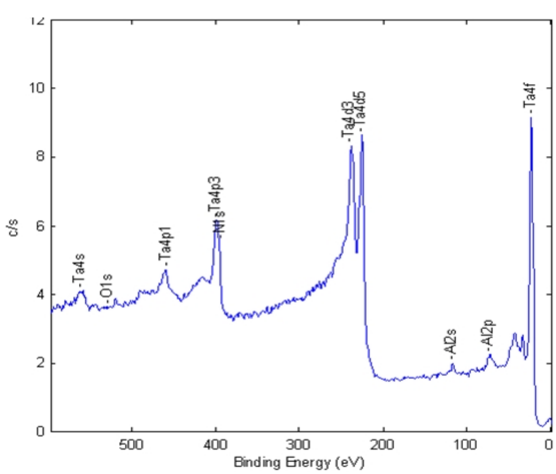


Figure. 3 XPS spectrum.

Step stress tests

The step stress tests (SST) have been performed to check the electrical strength and investigate a resistance change with respect to the applied energy in the thin film resister. Figure 4 shows the schematic of SST setup. For the SST, the input setting voltage was decided by the heat flux whose value is between 2.6 and 2.8 GW/m^2. The power was applied to a heater with increasing firing pulse width by 0.1 μs from 0.5 μs. The heater's resistance was calculated with an electric current measured by an oscilloscope.

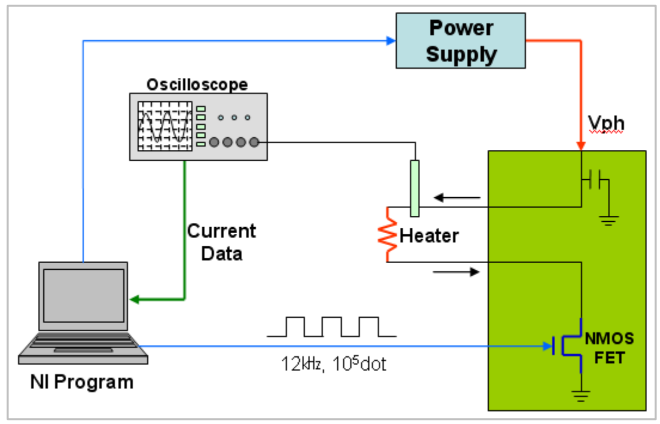


Figure 4. Schematic of step stress tests setup

Seven heater samples that have a resistance range from 37 to 390 Ω were prepared for investigating the stability of thin film resister. Heater shape was a square and its size was 28 by 28 μs. The resistance values are presented as a function of applied energy in Figure 5. Here, the heaters whose resistance are less than 130 Ω were more stable than the high one. There was no change in the heater which has lowest resistance (37 Ω). But, for the biggest one (390 Ω), the slope of resistance was very steep.

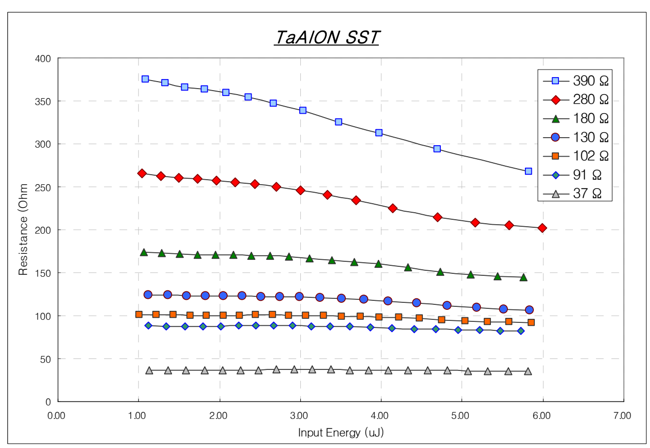


Figure. 5 Step stress tests of TaAlON resistor (37~390 Ohm)

To understand the size effect of heater, the heaters which have four different sizes were tested. The side lengths of square heater were 22, 26, 28 and 32 µm and its resistance was 116 *Ω/sq*. The change of resistance at the given energy is shown in Figure 6. There was not much difference from 1.0 to 3.0 µJ. After 3.0 µJ, the resistance was decreased at the relatively small size of heaters.

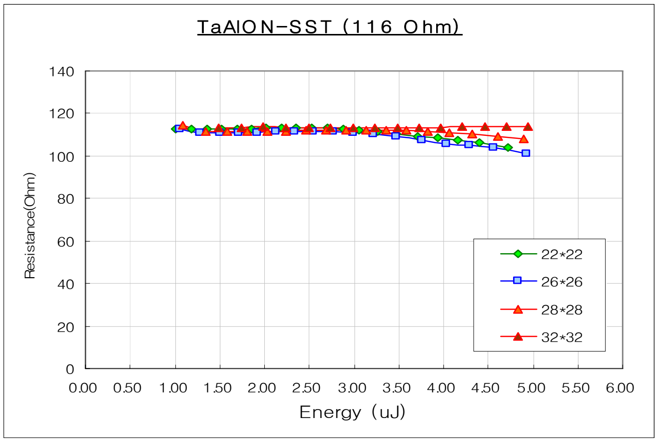
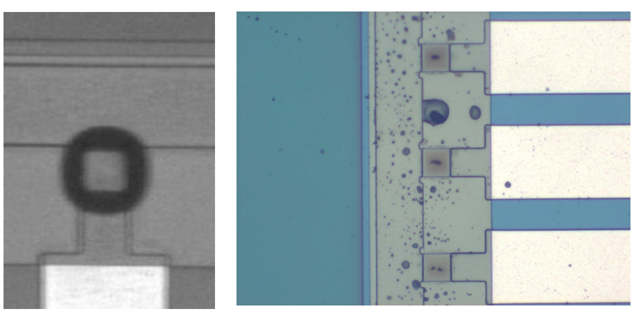


Figure. 6 Step stress tests of TaAlON resistor (116 Ohm)

Bubble tests

Open pool bubble tests [5] were conducted to visualize the bubble at a given power and check the lifetime of heater. A high speed CCD camera was utilized to monitor the bubble size and shape. DI water was used as a working fluid. About 1.18 µJ was applied to a square heater (22µm × 22µm) at a frequency of 5 kHz. The vapor bubble formed on a heater during the lifetime test is shown in Figure 7 (a). The surface of heater layer after 10^8 firing cycles is shown in Figure 7 (b).



(a) Vapor bubble (b) Heater surfaces

Figure. 7 Photograph of vapor bubble and heater surface.

Ink ejection visualization tests

The ejected ink droplets are monitored by visualization technique [6]. Two heads designed of split and square heater shown in Figure 2 (a) and (b) were prepared to check the stable ejection behavior of droplets and lifetime of thin film resister. The resistance of square and split were 130 and 450 Ohm, respectively.

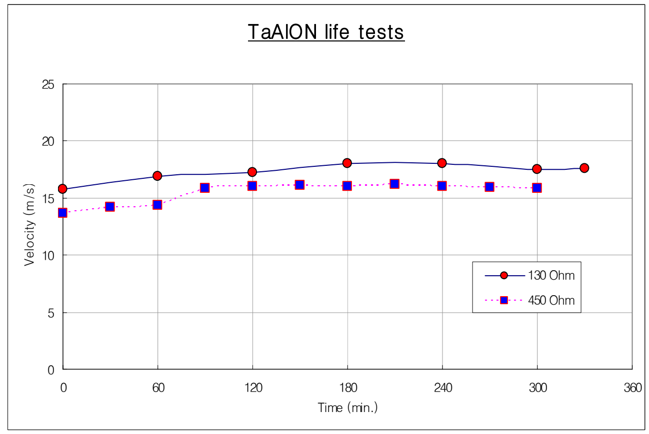


Figure. 8 Velocity of ejected ink droplets.

The shape of droplets was captured and its flight velocity was measured by the delay period with respect to the time. Figure 8 shows the velocity of ejected ink droplet. For square heater, a velocity was initially 15.77 m/s and its droplet shape was normal one. The firing frequency was 6 kHz and applied energy was 0.84 uJ. As shown in Figure 9, its droplet shape was consistent and velocity was increased a little during five and half hours (1.188×10^8 cycles). For a split heater, it shows a similar trend.

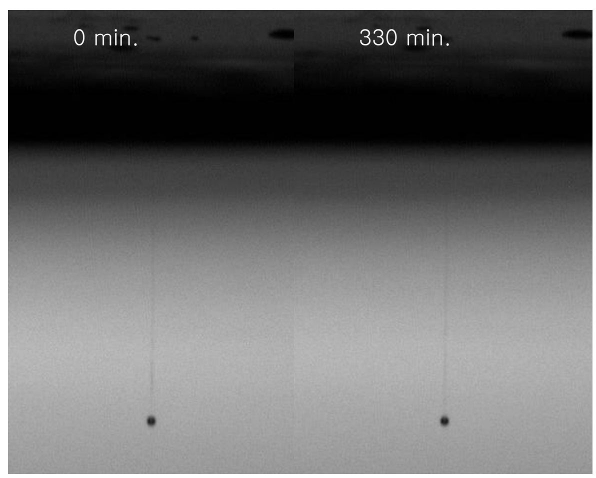


Figure. 9 Photograph of ejecting ink droplet.

Conclusions

Seven heaters that have a different resistance range from 37 to 390 Ω were made with the novel thin film material (TaAlON) by changing a gas flow rate in the sputter. The electrical tests showed that the characteristics of heater less than 130 Ω were more stable. To investigate the durability of thin film resistor, bubble tests were conducted with the heater whose resistance was 116 Ohm. The captured bubble shapes synchronized with the input pulse was uniform during 10^8 firing cycles. The ink ejection tests have been performed with square (130 Ohm) and split heaters (450

Ohm) deposited with the similar composition rate and showed that they satisfied with the lifetime (10^8 firing cycles). Based on above test results, it is considered that TaAlON is one of possible candidate as a heater material.

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Author Biography

Junwoo Suh received his Ph.D. degree in Mechanical Engineering from University of Cincinnati, Cincinnati, OH, U.S. in 2005. After one and half year as a research engineer at Delphi Research Labs, Detroit, MI, U.S., he joined Samsung Electronics Co. Ltd. (SEC), Korea in 2007, and has been working at Samsung Advanced Institute of Technology (SAIT), Korea since 2008.