Study of nib formation on a high-resolution thick film thermal head

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Abstract

For a dual-line 1200dpi thick film thermal printhead, the rendered dots are of elliptic shape, with aspect ratio of 1:1.5, due to the constraint of a smaller pitch in 1200dpi and the minimum nib line width required during nib line formation. This is one area for image quality improvement. Characteristics of conventional single-layer nib lines of different line width are studied. Based on the experimental result, a new formation approach of two-layer nib line structure is studied and tested to achieve the goal of producing an ideal round dot shape with aspect ratio of 1:1.

Introduction

The thermal printing technology is based on the principle of transferring heat from a high-resistance nib line to the thermal-sensitive media being contacted, and has the advantages of fast throughput and ease of maintenance. Utilizing this technology, the dual-line wide-format 1200dpi thick film thermal head has been developed[1] and may be used for high-end applications where halftone dots as high as 133 lpi can be rendered. However, the practical upper bound for consistent printing may be 120 lpi when the real characteristics such as mechanical tolerance, dot shape, etc, are taken into consideration. The most restrictive factor is the dot shape formed via transferring heat to the thermal-sensitive media. The elongated (in the media-feeding direction) oval dot shape may affect the gradation expression, rendering a less than desirable image quality. The adoption of different structures of heater elements has always been a research topic in quality improvement of thick film thermal printing systems[2, 3].

The circuitry of our 1200dpi thermal printhead makes use of an alternated conductive lead system. A heater nib line is formed by a direct dispensing system on top of the conductor pattern in alternated paths, and generates the Ohmic heat as the result of current flowing due to the voltage difference between conductors. After the heat is transferred to the thermal sensitive media, the image is rendered. Although a nib line width of 80µm can be formed stably, for consideration in real production 100-110µm width is adopted for a 1200dpi head. At this design choice, the aspect ratio of the dots formed is about 1:1.5 (the printhead- versus the feed-direction). In high-end graphic art applications, however, the aim is to produce an aspect ratio as close to 1:1 as possible.

Study of nib lines of different width

Using the current technology the affect of different width of nib line is studied based on the experimental result. By making the width of heater nib line narrower, with a fixed pitch between nibs, the aspect ratio may get closer to 1:1 and an ideal round dot shape be obtained.

However, there are two issues requiring careful consideration. One is the heater resistance paste material which has variations in the distributed state and the component particles (RuO_2, glass)[4]. The other is the formation of thick film heater nib line. To develop a 1200dpi printhead, a micro dispenser was developed to draw a high-resolution nib line[1]. The dispenser has the non-contact surface-following capability by means of back pressure sensing and, with a small nozzle (capillary of wire bonding), discharges the paste of thick film resistor material to form a nib line. However, variation does exist due to the state of paste and the specification of direct dispensing system. The narrower the drawn nib line is, the larger the affect of these variations becomes.

Note that on the dual-line 1200dpi thermal printhead the resolution of a single heater nib line is 600dpi. Shown in Figure 1 is the composite figure of a typical thick film thermal heater nib.

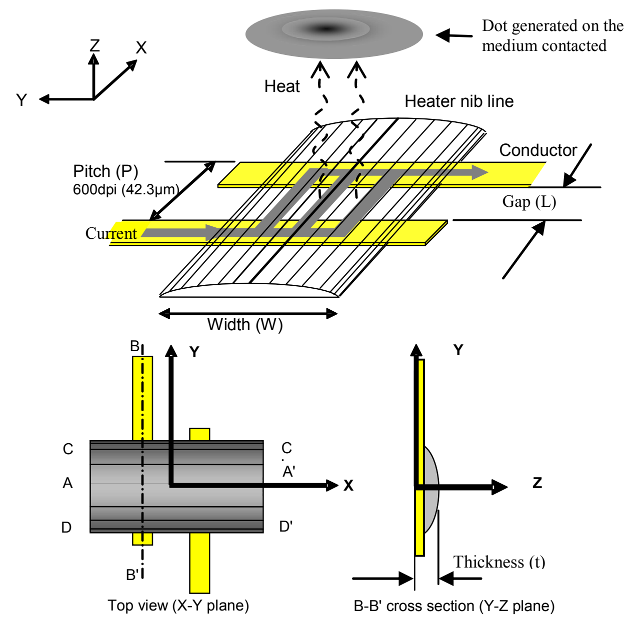

***Figure 1** A composite figure of a thick film thermal heater nib*

In our first study, three nib lines were drawn for use as test samples as listed in Table 1. Note that Gap (L) = Pitch (P) - width of conductor = 42.3 - 20 = 22.3µm, and that the differences in thickness (t, max height of nib line) are due to the viscosity of paste or its wet characteristics against the substrate.

Table 1 Three cases of heater nib line under study

Test sample	Width, W (µm)		Thickness t (µm)	Gap L (µm)	Pitch P (µm)
	Target	Actual			
Narrow	80	74	5	22.3	42.3
Middle	120	115	9	22.3	42.3
Wide	160	154	10	22.3	42.3

With these test samples, the following were evaluated:

- Variations in nib line width and resistance
- Electrical power-proof characteristics (Step Stress Test, SST)
- Print characteristics

Variations in line width and resistance

Listed in Table 2 are the measurements of nib line width and the corresponding 3-sigma variations and max deviations, defined as (max-min)/averaged width. The 3-sigma variations in resistance before adjustment are also listed. The zoomed top view after nib line formation is shown in Figure 2.

Table 2 Measurement and variation of line width and resistance

Test samples		Actual data			
Target width (µm)		Width (µm)	Width 3σ variation	Max deviation	Resistance variation
Narrow	80	74	6.8%	7.0%	33.4%
Middle	120	115	3.6%	3.6%	21.4%
Wide	160	154	3.7%	3.4%	18.4%

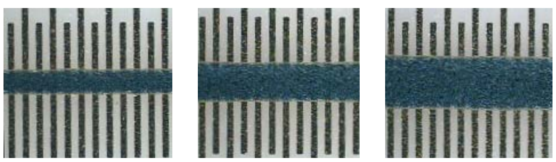

Figure 2 Zoomed top view of heater nib lines after formation

The magnitude of the surge on the base substrate is about the same in all three test samples, thus the influence in percentage is most profound in the case of narrow nib line. A thick film thermal head, after the nib line is formed, requires the procedure of adjusting resistance by means of electrical pulse trimming[5]. It is possible to trim the middle and the wide heater nib lines due to their moderate variations in resistance value. However, it is extremely difficult for the narrow nib line.

Electrical power-proof characteristics (SST)

The SST (Step Stress Test) is performed to evaluate the consistence of the nib line resistance under extreme working condition after the protective layer has been formed. The test is to apply a cyclic pulse sequence of a fixed power, with the cyclic period of 3 msec and power-on pulse width of 0.8 msec. The test power setting starts from 0.1 W and goes up in the increment of 0.01W. The averaged resistance is measured at each power setting. The percentage changes in resistance for all the three nib lines are shown in Figure 3.

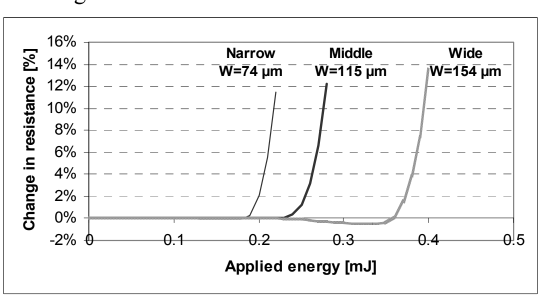

Figure 3 The SST characteristics of heater nib lines of different width

Print characteristics (dot shape)

Printing conditions:

- Medium: XP film (transparent thermal film made by Agfa)
- Applied time (power-on pulse width): 0.8 msec
- Single dot printing

The medium was fixed intentionally, while printing by applying a single pulse, to remove the factor of media movement. The print samples are shown in Figure 4. In the case of narrow nib line, a near-round (aspect ratio of 1:1.2) dot shape is acquired. The middle nib line, though more stable, produces an elongated dot shape with an aspect ratio of 1:1.7.

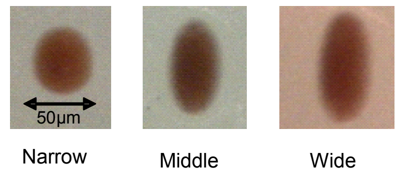

Figure 4 Printed single dot in test cases of different nib line width

By varying the applied power, different dot sizes can be obtained. Shown in Figure 5 is the relationship of dot width (X-diameter, in the nib line direction) versus the applied power for each nib line tested.

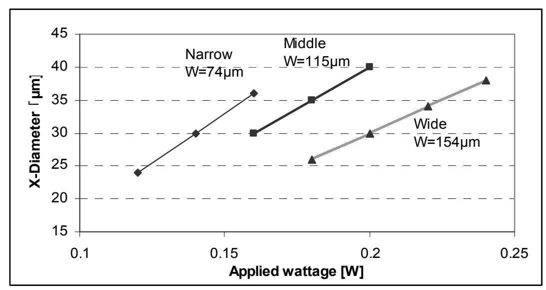

Figure 5 The relationship of dot width versus applied power

The optimal applied power for X-diameter=35µm (a proper dot width for 1200 dpi printing applications) and the maximum power causing a 10% increase in resistance in SST are listed in Table 3. Also listed is the percentage margin showing how far the optimal applied power is from the SST @ 10% resistance increase.

Table 3 The power-proof characteristics and proper printing conditions for nib lines of different line width

	Narrow	Middle	Wide
SST @+10% in R	0.204w	0.288w	0.384w
X-diameter=35µm	0.155w	0.18w	0.225w
Margin	24%	38%	41%

Analysis and preliminary conclusion

Three-dimensional thermal conduction analysis using finite element method[6] can be performed on a thick film thermal head with the structure shown in Figure 1. A simplified conceptual analysis, however, may as well provide some illustrative insight about the relationship between the geometrical configurations of the nib line and of the dot shape, and is briefly summarized here.

When the printhead circuitry is activated, the current flows from the high-voltage conductor to the low-voltage one along the nib line direction (X-axis). For a fixed voltage difference, the Ohmic heating rate is proportional to the effective electrical conductance between two conductors. Along the current path in X-axis direction, the effective conductance at any Y-axis position, of a tiny width Δy, is proportional to the cross-section area and hence the nib line height at that y position. Therefore the Ohmic heating rate at y=0 is maximal. Also due to the thinning at both flanking edges of the nib line, the typical distribution pattern of heat generating on the X-Y plane surface is like a dome[6].

The surface contour of the nib element in the Y-Z plane, Figure 1, can be approximated by an elliptic function $z=-ay^2+t$. The effective electrical conductance and the Ohmic heating rate are approximately proportional to the height of the nib line, and are maximal at y=0. The normalized heat generation rate (with 100% at y=0) along the conductor direction (Y-axis) for the three cases of different nib line width can be plotted in Figure 6.

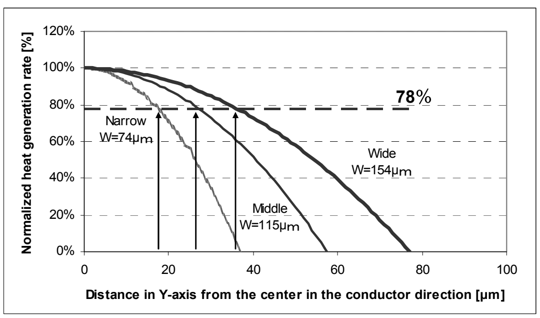

Figure 6 *The normalized heat generation rate with the center set to 100%*

The relationship of print characteristic versus the width of the heater nib line can be summarized below:

- The aspect ratio of dot shape is better (closer to a round shape) for a narrower heater nib line, but there may be problems in durability, width/resistance variations, etc. These drawbacks may be less obvious for a wider nib line, with 100µm width as the marginal value.
- The aspect ratio of dot shape can be approximated empirically by a function of the width and the thickness of a heater nib line. With the same line width, the aspect ratio of dot shape becomes smaller if the thickness of the nib line is larger.
- The SST and print characteristic also depend on the volume (~ width x thickness) of the nib element.
- For the single layer structure, it seems 78% of the full heat generation rate is what it takes to make a visible reaction on the printed media in forming the dot shape.

Proposed Improvement – two-layer structure

Note that the aspect ratio of dot shape is influenced by the form of heater nib line as mentioned above. When the width of a heater nib line is narrow (~74µm), the dot shape is almost close to an ideal (round) one, but it suffers from inconsistent durability, width/resistance variations, etc. The proposed approach is to look for an improvement method to form a better dot shape as in narrow nib line, but still keeps the same consistence as in wide nib line in addition to utilizing the current material and equipment. It is observed that the printing becomes invisible beyond the position in the conductor direction (Y-axis) where the thickness of nib line is lower than a cut-off value (~78%). This has motivated us towards the adoption of two-layer structure, which is practically feasible because the direct dispensing system can draw a nib line at a desirable width down to 80µm on glazed substrate.

The proposed 2-layer structure nib line to make an aspect ratio of 1:1 is based on the following considerations:

- By using a wider base layer, the advantages of durability and minimal resistance variation can still be kept.
- The base layer, however, should be thinner so that the dot shape won't be elongated in the conductor direction.
- To make up the thickness so that more heating rate and the visible dot shape can be produced, a top layer is added to have a more concentrated heat generation rate.

What we would like to have is a dot shape generated similar to or better than that by the middle width (115µm) and still keeping the advantages as in the wide nib line (150µm). The 2-layer structure proposed is shown in Figure 7 where two elliptic functions, $-a_By^2+t_B$ and $-a_Ty^2+t_T$, representing the surface contours of the bottom layer and the top layer, are plotted. The intersection point denotes the desirable dot length, 56µm (from y=-28µm to +28µm), in the conductor direction. Therefore, the top layer would have a fictitious base width of 74µm and max thickness of 10µm and the bottom layer is of width 150µm and a thickness of 5µm.

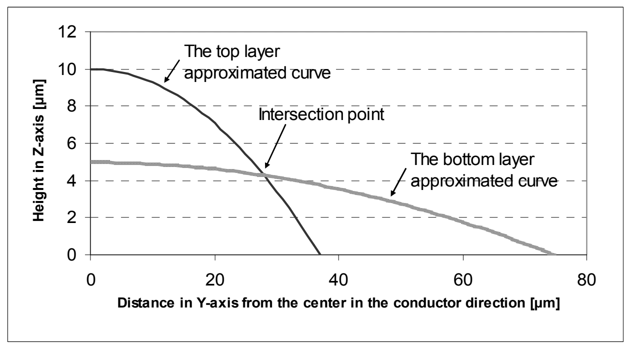

Figure 7 *Graphic representation of surface contour of two-layer structure*

A test sample and evaluation of two-layer structure

The heater nib line of the 2-layer structure is formed as shown in Figure 7 and the formation procedure is as follows. First, the bottom layer of 150µm in width and 5µm in thickness is formed utilizing a direct dispenser and gets dried. Then the top layer of 50-60µm in width and 5µm in thickness is added, also using a direct dispenser, and gets dried. Finally the thermal head is heated at high temperature. Since the bottom layer after dryness tends to absorb heater resistance material (paste), the width of top layer does not spread, easing the formation of a narrower nib line. The enlargement of the upper surface after two-layer formation is shown in Figure 8.

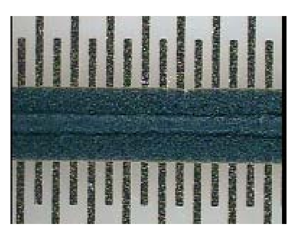

Figure 8 *Enlargement of the upper surface of the two-layer heater nib line*

The physical dimensions after final formation are: top/bottom layer width: 50μm/170μm, total thickness (max height at the center line): 11μm. The height at the intersection point of the top and bottom layers is about 4μm. The top layer is formed uniformly on top of and within the boundary of the bottom layer. The nib line formed this way is then used for evaluation. Listed in Table 4 is the comparison of nib line characteristics for different test cases.

Table 4 Nib line characteristics comparison

	Narrow	Middle	Wide	2-layer
Resistance variation	33.4%	21.4%	18.4%	18.2%
SST @+10% in R	0.204w	0.288w	0.384w	0.328w
X-diameter=35μm	0.155w	0.18w	0.225w	0.188w
Margin	24%	38%	41%	43%

The resistance variation of 2-layer structure is about the same as Wide line width in single-layer structure. The influence of the surge of the top layer is also small. In addition, further trimming can reduce the variation in resistance to less than 2%.[5]

Among the SST curves for different nib line structures, the two-layer structure ranks between the Middle and Wide nib lines.

The applied energy for which a 35μm X-diameter (i.e., dot width) of printing can be obtained is almost the same as Middle nib line. When the margin is calculated from the result of SST and the print characteristics (at X-diameter=35μm), the two-layer structure is the best among all the test cases.

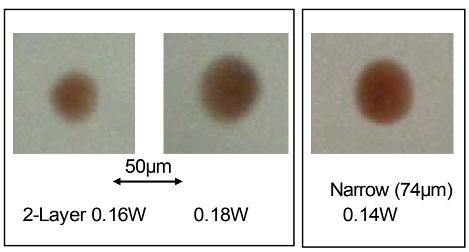

Figure 9 *Enlargement of single dot shape printed using 2-layer structure*

The enlargement of single dot shape obtained by printing without moving the media is shown in Figure 9, with Narrow nib line of single-layer structure also displayed for comparison.

Other observations and preliminary conclusion

To verify the state of thermal storage, the thermal transient characteristic is measured using a micro surface thermometer. The measured curves of 2-layer structure and Middle width are shown in Figure 10, with both exhibiting similar characteristics.

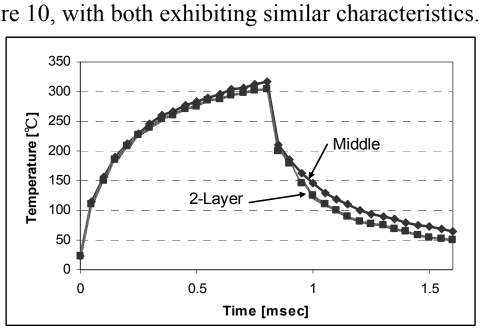

Figure 10 *Thermal transient characteristics (measured in the sensing Φ20μm area of heater nib central part)* T_{on}*=0.8 msec, W=0.18 w*

The close resemblance of thermal transience between the 2-layer test sample and the Middle line width (115μm, with thickness of 9μm) of single-layer structure coincides with the observation that the optimal applied energies (for 35μm dot-width printing) are about the same for these two test cases.

Note that in the case of single-layer structure the nib line (like the bottom layer in 2-layer structure) is drawn on a glazed substrate, there is a spread of width due to the material characteristics of heater resistance paste. For 2-layer structure, in contrast, after the bottom layer has been dried, the top layer line is formed on top of it and shrinks about 30%.

The test result does confirm the design idea that, by using the 2-layer structure, a dot shape similar to or better than that by the Middle width of single-layer structure may be generated while the advantages of durability, consistence in resistance, etc., as in the Wide nib line, are still preserved.

Summary and future direction

For single-layer structure, experiments have been performed on nib lines of different width. While a narrow nib line may generate an ideal round dot shape, a wide nib line has the more desirable characteristics, such as durability, small resistance variation, etc., required for production

A 2-layer structure composed of a wide bottom layer and a narrow top layer seems to be a promising solution. A test sample is made and exhibits a round dot shape and the desirable characteristics for production. However, the adjustment method of resistance in forming a 2-layer structure during production is different from the current single-layer formation. To establish a more efficient procedure for resistance adjustment is an R&D topic being pursued.

References

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Author Biography

Takeshi Toyosawa obtained his B.S. in Chemistry from Akita University, Japan in 1979. He worked at GRAPHTEC Corporation Research and Development from 1979 to 2004. Since 2005 he has been with OYO Geospace Corp, and is continuing R and D in wide format high resolution thermal print head.