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(71) Applicant : **XEROX CORPORATION**
Xerox Square
Rochester New York 14644 (US)

(72) Inventor : **Torpey, Peter A.**
No. 5, Melissa Lane
Penfield, New York 14526 (US)

(74) Representative : **Goode, Ian Roy**
Rank Xerox Patent Department Albion House,
55 New Oxford Street
London WC1A 1BS (GB)

(54) Thermal ink jet printhead having an increased drop velocity.

(57) A thermal ink jet printhead for ejecting and propelling ink droplets on demand is disclosed. The ink droplets travel along a flight path from orifices in the printhead toward a recording medium such as paper by momentarily heating the ink. The printhead includes at least the elongated channel that forms a straight ink flow path therethrough. The channel has an orifice at one end and an inlet at the other end for communicating with an ink reservoir. A heating element is disposed inside the channel and it has a surface that contacts the ink. A constrictor is placed in the channel near the orifice so that the velocity of the ink flow through the orifice is increased.

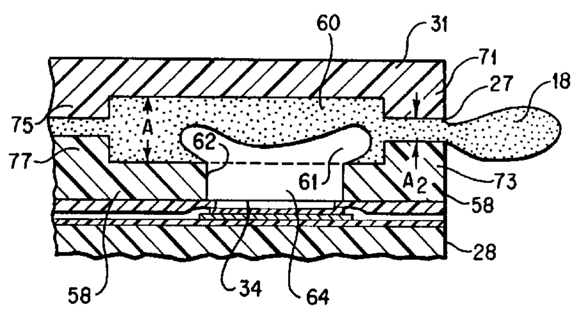

FIG. 3

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Jouve, 18, rue Saint-Denis, 75001 PARIS

The invention relates generally to thermal ink jet printing systems, and more particularly to an improved thermal ink jet printhead having an increased drop velocity.

In drop-on-demand ink jet printing systems, a printhead uses thermal energy to produce a vapor bubble in an ink-filled channel in order to expel a droplet of ink. This type of printing is known as thermal ink jet printing. As disclosed in U.S. Patent No. 4,663,359 to Ayata et al., such printing systems generally include one or more ink-filled channels. One end of each channel is in fluidic communication with a relatively small ink reservoir. The opposite end of each channel, referred to as the nozzle, is an opening through which the ink can be expelled onto a recording medium such as paper. A thermal energy generator, usually a resistor, is located in each of the channels at a predetermined distance from the nozzle. The resistors are individually addressed with a current pulse to momentarily vaporize the ink and form a bubble that will expel an ink droplet. As the bubble grows, the ink bulges from the nozzle, where it is restrained by surface tension. As the bubble begins to contrary the ink remaining in the channel continues to move toward the collapsing bubble, causing a volumetric contraction of the ink at the nozzle. This contraction results in the separation of the bulging ink from the nozzle, thus producing a droplet. The velocity and momentum of the droplet, which is provided by the acceleration of the bubble as it grows inside the channel, is substantially along a straight line directed toward the recording medium.

For a number of reasons, it is important in bubble jet thermal printheads to keep the momentum and velocity of the ink droplets relatively high. When such conditions are met, any potential misdirectionality of the droplets caused by wetting effects at the nozzle will be minimized, assuring stable, uniform printing. Several methods of imparting high velocity and momentum to the droplets are known. In one method, the heating element is placed closer to the nozzle so that only a relatively small quantity of ink needs to be acted upon as the bubble grows and expands. Consequently, the bubble imparts a greater momentum to this small quantity of ink than it would if the heating element were placed farther from the nozzle. In another method, the duration of the current pulse provided to the heating element is increased to generate more thermal energy. This thermal energy increases the quantity of heat present in the ink prior to the nucleation of the micro- sized vapor bubbles, yielding a more rapid or explosive bubble growth.

However, these known methods of increasing droplet velocities are extremely limited because of the phenomenon known as "blowout". Blowout or ingestion occurs when a growing bubble within a channel expands so greatly that it communicates closely with outside air such that the boundary between bubble and outside air may be broken, allowing ingestion of outside air into the low pressure bubble. Because of this result, ingested air may be trapped in the channel. This air bubble can seriously degrade the nucleation or ejection process of the ink as it forms a bubble, producing a misdirected, weakly propelled droplet. Since placement of the heating element closer to nozzle and an increase in the duration of the heating pulse both produce a greater rate of bubble growth, the likelihood of blowout is also increased.

US-A-4,638,337, which is assigned to the same assignee as the present invention and which is incorporated herein by reference, reduces the problem of blowout while maintaining an increased bubble velocity. In this reference, the heating elements generating the bubbles are positioned in a recess located in the lower surface of the channel. The walls of the recess are perpendicular to the lateral flow of ink in the channel. These walls constrain the expanding bubble from growing in the lateral direction and force the bubble to grow in a direction perpendicular to the direction of ink flow. This arrangement reduces the likelihood of blowout, because the bubble does not expand as rapidly toward the nozzle. Therefore, the heating element may be placed closer to the nozzle and the duration of the pulses to the heating element may be increased without overly increasing the likelihood of blowout.

In order to further minimize the misdirectionality of the droplets as they exit the nozzle, there is a need to increase the droplet velocity still further without at the same time exacerbating the air ingestion problem that leads to blowout.

The present invention relates to a thermal ink jet printhead for ejecting and propelling ink droplets on demand that overcomes the deficiencies noted above. The present invention provides a thermal ink jet printhead, including at least one elongated channel that forms a straight ink flow path therethrough. The channel has an orifice at one end for ejecting the ink and an inlet at the other end for communicating with an ink reservoir. A heating element is disposed inside the channel and it has a surface that contacts the ink. A constrictor is placed in the channel near the orifice so that the velocity of the ink flow through the orifice is increased.

By constricting the cross-sectional area of channel near the orifice, the volume flow rate of the ink is increased, thereby increasing the velocity of the droplet expelled from the nozzle. This increase in velocity is advantageously accomplished without supplying additional heat to the ink and without moving the heating element closer to the nozzle. As a result, droplet velocity is increased without increasing the probability that blowout will occur.

In an alternative embodiment of the invention, an additional constrictor is disposed inside the channel near the inlet thereof. This constrictor aids in balancing the inertial forces against which the bubble expands.

The above is a brief description of some of the deficiencies in disclosed ink jet printheads and the advantages of the present invention. Other features, advantages and embodiments of the invention will be apparent to those skilled in the art from the following description, accompanying drawings and appended claims.

Figure 1 is a schematic isometric view of a carriage type thermal ink jet printing system incorporating the present invention;

Figure 2 is a schematic cross-sectional side view of a known printhead channel; and

Figure 3 is a schematic cross-sectional side view of a printhead channel constructed according to the principles of the invention.

A typical carriage type, multicolor, thermal ink jet printing device 10 is shown in Figure 1. A linear array of ink droplet producing channels is housed in each printhead 11 of each ink supply cartridge 12 which may optionally be disposable. One or more ink supply cartridges 12 are replaceably mounted on a reciprocating carriage assembly 14 which reciprocates back and forth in the direction of arrow 13 on guide rails 15. The channels terminate with orifices or nozzles aligned perpendicular to the carriage reciprocating direction and parallel to the stepping direction 17 of a recording medium 16, such as paper. Thus, the printhead prints a swath of information on the stationary recording medium as it moves in one direction. Prior to the carriage and printhead reversing direction, the recording medium is stepped by the printing device a distance equal to the printed swath in the direction of arrow 17 and then the printhead moves in the opposite direction printing another swath of information. Droplets 18 are expelled and propelled to the recording medium from the nozzles in response to digital data signals received by the printing device controller (not shown), which in turn selectively addresses with a current pulse the individual heating elements located in the printhead channels a predetermined distance from the nozzles. The current pulses passing through the printhead heating elements vaporize the ink contacting the heating elements and produce temporary vapor bubbles to expel droplets of ink from the nozzles.

Figure 2 shows a cross-sectional view along the length of a known channel in a thermal ink jet printhead. A reservoir (not shown in this Figure) continuously supplies the ink 60 to the back section (i.e. the left-hand side in Figure 2) of the channel by capillary action. Initially, the ink 60 located at the nozzle 27 forms a meniscus, the surface tension of which prevents the ink 60 from escaping therefrom. Figure 2 shows the channel at a time when a heating element 34 in a recess 64 has been addressed with a current pulse to vaporize the ink 60 contacting the surface of the heating element 34 to form a bubble 61. The bubble 61 causes the ink to bulge from the nozzle 27, producing a droplet 18 that is seen in Figure 2 just prior to its breaking away as a discrete droplet. The recessed walls 62 of the insulative layer 58 restrict the lateral spread of the vapor bubble 61, forcing the bubble 61 to grow in a direction perpendicular to the surface of the heating element 34. As a result, the blowout phenomenon is reduced.

Figure 3 shows a cross-sectional view across the length of the channel of the present invention. Like reference numerals are used for the components in Figure 3 that correspond to those in Figure 2. In order to increase the velocity and momentum of the droplet 18, the nozzle 27 is constricted by constrictors 71 and 73 so that its cross-sectional diameter A_2 is less than the diameter A_1 in the mid-section of the channel. The reason this constriction leads to an increased velocity is as follows. Conservation of mass requires that the volume flow rate Q_1 in the mid-section of the channel having area A_1 be equal to the volume flow rate Q_2 in the front-section of the channel near the nozzle having an area A_2. If V_1 is the velocity of the ink 60 in the mid-section, and V_2 is the velocity of the ink 60 in the front-section, then:

$$Q_1 = V_1 x A_1 = V_2 x A_2 = Q_2 \quad (1)$$

Therefore, the velocity V_2 at the exit of the nozzle 27 is:

$$V_2 = V_1 x (A_1/A_2) \quad (2)$$

Equation 2 indicates that as the area A_2 decreases relative to A_1, the velocity of the ink 60 at the exit of the nozzle 27 increases. Although this equation is only approximately accurate because V_1 is not completely independent of the channel geometry, it does accurately point out the general trends.

As seen in Figure 3, it is advantageous if the rear-section of the channel is constricted by constrictors 75 and 77 in a manner similar to the front- section. This additional constriction esures that other performance aspects of the printhead will be maintained at values similar to those of the known printhead seen in Figure 2. For example, as the bubble 61 expands it exerts a force both toward the nozzle 27 and back toward the ink reservoir. Of course, it is advantageous if the bubble 61 exerts a greater force toward the nozzle 27 than toward the reservoir so that the droplet 18 is forced from the nozzle at a maximum velocity. If only the front-section of the channel were constricted, the bubble 61 would tend to exert an even greater fraction of its force back toward the reservoir, decreasing the force on the droplet 18 and hence decreasing the maximum velocity of the droplet 18. For this reason, it is advantageous to balance the forces exerted by the bubble 61 by equally constricting the front and back sections of the channel.

The channel may be formed by any of the various techniques known in the art. For example, U.S. Patent No. 4,638,337, which has been incorporated herein by reference, produces the upper substrate 31 and the lower substrate 28 from polished silicon wafers. Grooves are formed in the upper substrate 31 to form the channels. A number of protective and insulating layers may be formed on the lower substrate 28 before it is joined with the upper substrate 31. For example, a thick film insulative layer 58 formed from a polyimide material may be deposited on the lower substrate 28. The layer 58 can be etched away at a particular location to form the recess 64 containing the heating element 34. Finally, the surface of the upper substrate 31 is bonded to the lower substrate 28 so that the heating element 34 is positioned in the channel.

The front and back sections of the channel may be constricted in various ways that depend on the fabrication process used to form the channel. Any fabrication process known in the art may be used. For example, one simple method of producing the constriction is to etch the upper substrate 31 so that the mid- section of the channel is wider than the front and back sections. This etching process produces the upper-front constrictor 71 and upper-back constrictor 75 seen in Figure 3. A further constriction can be achieved by depositing an additional insulative layer 58 on what will become the front and back sections of the channel to form the lower-front and lower-back constrictors 73 and 77.

In one particular embodiment of the invention, the mid-section of the channel is etched to a width of about 70 microns (and thus about 49 microns in height) and the front and back sections are etched to a width of about 60 microns (and thus about 42 microns in height). This configuration yields a ratio of A_1 to A_2 of 1.36, thereby increasing the velocity of the ink at the nozzle by 30- 35% compared to a channel that is not narrowed. If a typical droplet velocity in a straight channel is 7-8 meter/second, a channel having a constriction such that $A_1/A_2 = 1.36$ will produce a droplet velocity as great as 9.1-10.8 meter/second

The above is a detailed description of a particular embodiment of the invention. The full scope of the invention is set out in the claims that follow and their equivalents. Accordingly, the claims and specification should not be construed to unduly narrow the full scope of protection to which the invention is entitled.

Claims

1. A thermal ink jet printhead for ejecting and propelling ink droplets (18) on demand along a flight path from at least one orifice (27) in the printhead toward a recording medium (16) spaced therefrom by momentarily heating the ink (60), said printhead comprising:

   at least one elongated channel defining a straight ink flow path therethrough and having an orifice at one end, the other end serving as an inlet for communicating with an ink reservoir;

   a heating element (34) disposed internally of the channel and having a surface to contact the ink; and

   means (71, 73) for constricting the flow of ink (60) through the orifice (27) to increase the velocity of the ejected ink (18).

2. The thermal ink jet printhead of claim 1, further comprising means (75, 77) for constricting the flow of ink (60) through the inlet of said channel.

3. The thermal ink jet printhead of claim 1 or 2, further comprising a recess (64) in the channel, said heating element (34) surface being disposed in said recess.

4. The thermal ink jet printhead of claims 1, wherein

   said at least one elongated channel comprises a straight capillary channel within the printhead that interconnects an orifice (27) with an ink supplying reservoir, and said printhead comprises

   an upper substrate (31) having a surface with at least one straight groove, said groove having a front, back, and mid-section, said mid-section being wider that said front and back sections;

   a lower substrate (28) having a face that includes a predetermined portion on which at least one heating element (34) is disposed; and

   a thick film insulative layer (58) overlaying the lower substrate (28) except said portion on which at least one heating element is disposed, said upper (31) and lower (28) substrates being bonded together so that the groove is coplanar with the lower substrate face to form said at least one channel containing said at least one heating element (34).

5. The thermal ink jet printhead of claim 4, wherein said predetermined portion is recessed from said lower substrate face.

6. The thermal ink jet printhead of claim 4 or 5, wherein said upper substrate (31) comprises silicon.

7. The thermal ink jet printhead of any of claims 4 to 6, wherein said insulative layer (58) comprises a polyimide material.

8. The thermal ink jet printhead of any of claims 4 to 7, wherein said mid-section of the groove has width (A) of 70 microns and said front and back sections have a width (A^2) of 60 microns.

9. The thermal ink jet printhead of any of the preceding claims, wherein:

said means for constricting comprises at least one constrictor (71, 73, 75, 77).

10. The apparatus of any of the preceding claims, wherein: means for constricting the flow of ink through the orifice and/or inlet comprises means for constricting the flow of ink by approximately 30-35%.

11. A method of ejecting and propelling ink droplets on demand along a flight path from orifices in a printhead toward a recording medium to print images thereon, said method comprising the steps of:

filling an ink supply cartridge communicating with a channel inlet of at least one elongated channel so that ink fills the channel by capillary action;

providing means for constricting the flow of ink through the orifice forming an end of the channel to increase the velocity of the ejected ink; and heating momentarily a portion of the channel contacting the ink to eject an ink droplet therefrom upon receiving a data signal.

12. The method of claim 11, wherein the step of heating a portion of the channel occurs in response to data signals being received by a printing controller.

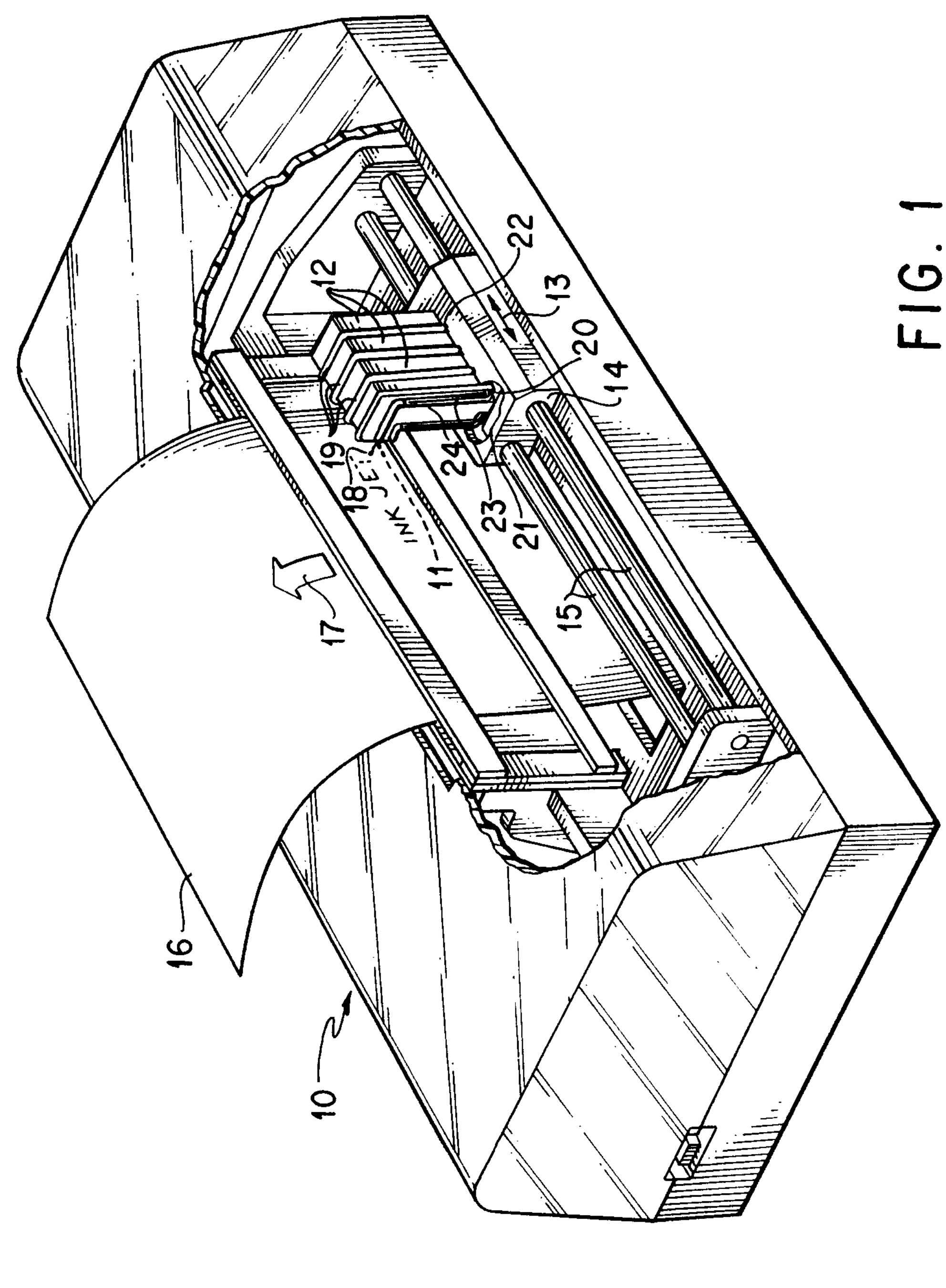

FIG. 1

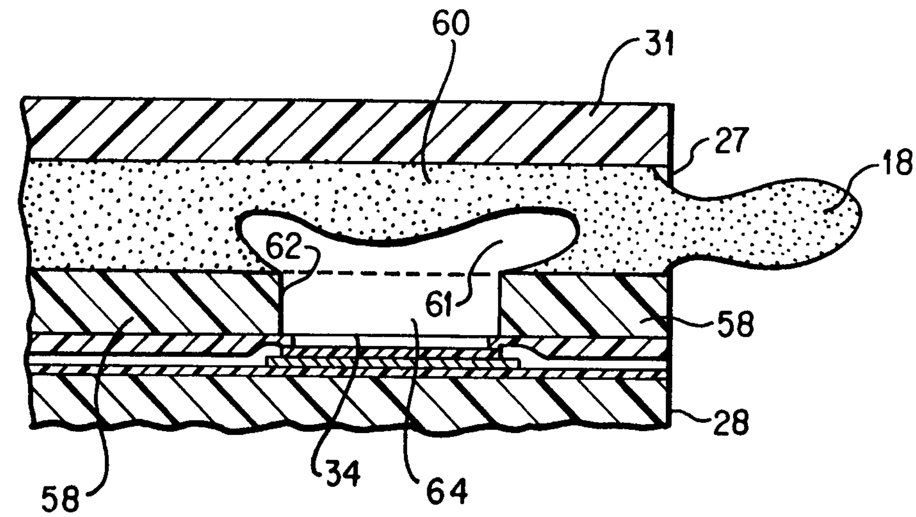

FIG. 2
(PRIOR ART)

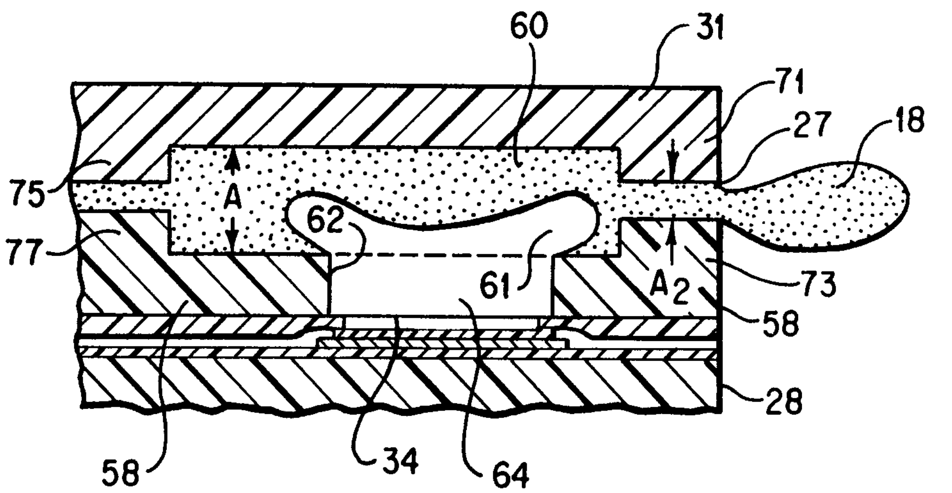

FIG. 3