(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number : **0 571 127 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number : **93303662.6**

(51) Int. Cl.^{5} : **B41J 2/14**

(22) Date of filing : **12.05.93**

(30) Priority : **22.05.92 US 886577**
31.08.92 US 938062

(43) Date of publication of application :
24.11.93 Bulletin 93/47

(84) Designated Contracting States :
DE FR GB IT

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(54) Monolithic thermal ink jet print head for phase-changing ink.

(57) A thermal ink jet print cartridge (24) that integrates pressure regulation, ink filtration, and melt-on-demand and quick turn-on, temperature regulation heaters into a monolithic print head. Heat spreading is accomplished by thermally-conductive elements (33) within the pen body and heaters adapted to heat the ink (32) prior to ejection. A quick-on, temperature regulating heater (44) is disposed adjacent to an ink drop generator. Melt on-demand heaters (45, 45a) may also be employed that are disposed in contact with heat spreading elements (33) to heat the phase-change ink (32) to a temperature above its melting point to allow it to flow to the drop ejection chambers (52). Pressure regulation is accomplished by a bubble generator (46) having an orifice acting together with a flexible bladder (30). The bladder (30) has a vent (31) to the outside of the cartridge (24) for maintaining a relatively constant partial vacuum as the air in the cartridge expands and contracts due to heating and cooling. Pressure regulation and ink filtration components are integrated into a substrate (41) containing the print engine. Individual filters (70) in the substrate (41) for each drop generator (40) comprising an array of holes takes the place of a single feed-through hole in conventional printers thereby integrating the ink filtration and ink supply functions. The print head uses a freezing mechanism to secure and seal the bubble generator orifice (46) to maintain a subatmospheric internal pressure within the ink cartridge. The phase change of hot-melt ink (32) seals the bubble generator (46) when the print cartridge (24) is in standby mode or when it is removed from the printer. Removal of an active print cartridge (46) from the printer is delayed until the bubble generator orifice (46) freezes. This is accomplished by turning off the temperature regulating heater (44) that maintains the ink (32) in the vicinity of the bubble generator (46) in a liquid state, and dissipating the heat of fusion to form a solid plug or skin within or over the bubble generator (46).

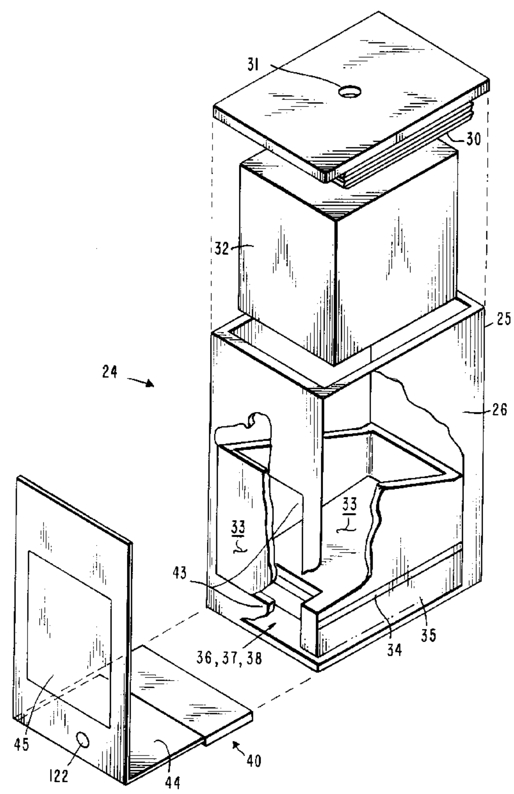

Fig. 3.

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The present invention relates to thermal ink jet printers and, more particularly, to thermal ink jet print heads fabricated on flexible plastic substrates.

A monolithic thermal ink jet print head typically uses a flexible plastic substrate for its primary structural element. A drop generator comprising thin-films, barriers, an orifice plate, and electrical interconnects is integrated into the plastic substrate. A printing cartridge employing "hot-melt" (or phase-change) ink that incorporates the monolithic print head requires the use of pressure regulation, ink filtration, melt-on-demand, and quick turn-on heaters. Heretofore, such requirements were met by using additional separate components with the monolithic print head, adding to the cost of assembly and the overall mechanical complexity of the ink jet print cartridge.

Pressure regulators employing bubble generators have been developed for thermal ink jet print cartridges employing liquid inks, and are disclosed in U.S. Patent Application No. 07/752,107, filed August 29, 1991. Practical implementation of a bubble generator in a liquid ink system usually employs elaborate manifolding and pressure compensation to prevent loss of ink due to thermal or altitude cycling, and loss of internal vacuum during pen handling (when the bubble generator might not be covered by a layer of liquid). Bubble generators have been fabricated from molded holes in plastic, drilled or punched holes in metal, and formed holes in a plastic film. The plastic film bubble generator is used as a discrete component in liquid thermal ink jet print cartridges and is not integrated with the nozzle plate or substrate structure.

It is conventional to use cartridge heaters and other electrically-resistive means to generate thermal energy to provide phase-change and temperature control for ink jet printers employing phase-change inks. Ink printing mechanisms for phase-change ink have employed freezing of the ink in the drop ejection orifices to prevent loss of volatiles or other degradation of the ink during standby modes and to prevent discharge of hot liquid ink during removal of the print head from the printer.

As to ink filtration, in many conventional thermal ink jet print cartridges, ink passes through a filter, an ink pipe, and a slot (or hole) in a silicon or glass substrate before entering the drop generators for ejection. The filter is typically a woven wire mesh which rejects particles greater than typically 10-20 microns in diameter. The filter is typically stamped from sheet material, and inserted into the print cartridge body where it is heat-staked or swaged into place.

In view of the complexities of the above-described thermal ink jet print cartridge systems, it is an objective of the present invention to improve on them and to further reduce the cost and simplify their assembly by integrating pressure regulation, ink filtration, melt-on-demand, and quick turn-on heaters into the monolithic print head. It is a further objective of this invention to form the ink containment, mechanical alignment, and heat transfer features concurrently with other processing steps, thus achieving additional functionality with a minimum of additional processes.

SUMMARY OF THE INVENTION

The foregoing and other objectives are accomplished by increasing the level of functional integration of a thermal ink jet print cartridge. The thermal ink jet print cartridge of the present invention includes means for containing and feeding solid ink, a mechanical alignment mechanism that aligns the ink jet cartridge for accurate ink dispersal, and a heat-spreading mechanism. Ink containment and alignment are accomplished using a sealed pen body comprised of plastic or other suitable material. Heat spreading is accomplished by thermally-conductive elements provided within the pen body. Pressure regulation is accomplished by a bubble generator that co-operates with a flexible bladder. Pressure regulation and ink filtration components are integrated into a substrate containing the print engine.

The print head of the present invention employs a freezing mechanism to secure and seal the bubble generator to maintain a subatmospheric internal pressure within the ink cartridge. The bladder has a vent to the outside is provided for maintaining a relatively constant partial vacuum as the air in the pen body expands or contracts due to heating or cooling. In addition, the present invention comprises a heater that is integral to the immediate structure of the drop generator and is fabricated from the same materials and by means of the same processes. The present invention provides an improvement over prior art print head designs by eliminating mesh filter and assembly operations by providing individual filters on the plastic substrate for each drop generator or for a group of drop generators. An array of holes takes the place of a single feed-through hole in conventional thermal ink jet printers, thereby integrating the ink filtration and ink supply functions.

Another feature of the present invention is that it utilizes the phase change of hot-melt ink to seal the bubble generator when the print cartridge is in standby mode or when it is removed from the printer. Removal of an active print cartridge from the printer is delayed until the bubble generator orifice freezes. This is accomplished on-demand by removing the local source of heat that maintains the ink in the vicinity of the bubble generator in a liquid state, and dissipating the heat of fusion of sufficient liquid ink to form a solid plug or skin within or over the bubble generator. This simple mechanism accomplishes the containment of ink and maintenance of partial vacuum without necessitating multiple extra components and functions as in previous designs.

Another feature of the present invention is that it provides a plurality of heaters and heat spreaders that provide and couple thermal energy to melt the phase-change ink on-demand and to provide quick turn-on. These two heaters are incorporated into the substrate and forms part of the drop generator or print engine. However, the separate melt-on-demand heater may be dispensed with, if desired, although it is ordinarily viewed as an essential element of the print cartridge. If desired, pen design may be simplified by supplying solid ink on-demand to the ink feed chamber where ink in liquid phase is present. The liquid ink is delivered to the print engine at a temperature above its melting point to control viscosity. The excess temperature above the melting point is used to melt the ink, as required, thus eliminating the need for a separate melt-on-demand heater, but requires a dual-function quick-on and temperature regulating heater to supply the heat of fusion to the ink.

BRIEF DESCRIPTION OF THE DRAWINGS

The various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

Fig. 1 is a perspective view of a thermal ink jet printer printing a band e.g., a row or rows of pixels, across a piece of paper;

Fig. 2 is a side view in cross section of a print cartridge embodying the invention and employed in the printer of Fig. 1;

Fig. 3 is an exploded partially cutaway view of the print cartridge incorporating the principles of the present invention;

Fig. 4 is a plan view of the front side prior to folding of the integrated monolithic print engine employed in the print cartridge of Fig. 2;

Fig. 5 is a plan view of the back side prior to folding of the print engine of Fig. 4;

Fig. 6 is a perspective view after folding of the integrated monolithic print engine of Figs. 3 and 4;

Fig. 7 is an enlarged fragmentary view of the front side of the integrated monolithic print engine of fig. 3 showing a detail of an integral ink filter made of an array of filter holes;

Fig. 8a is a cross sectional view of a drop generator showing a folded substrate and an array of filter holes;

Fig. 8b is a cross sectional view of the drop generator of Fig. 8a;

Fig. 9 is a schematic drawing of a control system for a solid ink print cartridge illustrating regulation of ink level and regulation of ink temperature;

Fig. 10 is a schematic drawing of a second embodiment of a print cartridge in accordance with the present invention employing a dual melt-on-demand heater and control system; and

Fig. 11 illustrates the integrated monolithic print engine employed in the print cartridge of Fig. 10.

DETAILED DESCRIPTION

Referring now to the drawings, FIG. 1 shows a perspective view of a thermal ink jet printer 10 comprising a carriage 11 that rides on guide rails 12, 13 and is mechanically scanned in a horizontal direction, as is indicated by a first arrow 14. The horizontal scan action is controlled in a conventional manner by a computer-controlled DC motor (not shown) in conjunction with a single channel linear encoder (not shown) that is used to close a control loop around the motor. A print media such as paper 15 is provided and may be accordion-fold paper or cut-sheet paper. A paper feed mechanism (not shown) moves the paper 15 transversely to the horizontal scan direction, as is indicated by a second arrow 16. As the carriage 11 travels across the paper 15, a plurality of ink drops are ejected, causing a printed band 17 comprised of rows of individual dots to appear on the paper 15.

FIG. 2 is an enlarged side view in cross section of an improved print cartridge 24 that may be employed in the carriage 11 of the printer 10 shown in FIG. 1. The print cartridge 24 comprises a hollow, air-tight container or pen body 25, that may be made of plastic, for example, having a plenum chamber 26, an ink containment reservoir 27, and an ink feed chamber 28. A flexible bladder 30 is disposed in the plenum chamber 26 and is attached to the interior of the upper wall of the pen body 25. A vent 31 provides a passage from the interior of the bladder 30 to the exterior of the pen body 25. As mentioned above, the pen body 25 comprises an air-tight container. Air in the plenum chamber 26 is typically at a partial vacuum of between one and four inches of water column. As will be explained hereinafter, the air in the plenum chamber 26 becomes heated during operation of the printer 10. The air in the plenum chamber 26 expands when it is heated. The bladder 30 has a stiffness necessary to maintain the partial vacuum in the plenum chamber 26 and collapses by an amount the air expands, thus maintaining the pressure inside the pen body 25 nearly constant while allowing significant expansion of the trapped air in the plenum chamber 26.

The ink containment reservoir 27 contains a quantity of solid ink 32. The ink 32 is a phase-change ink that is stored in the form of a solid block. The block of ink 32 rests on an upper heat spreader 33 which, when heated, liquifies a portion of the bottom surface of the block of ink 32 that is in contact therewith, in the same way that a hot griddle melts a block of butter. The upper heat spreader 33 is made of a metal, such as aluminum or copper, that is a good thermal conductor. A thermal insulator 34 is disposed below and between the upper heat spreader 33 and a lower heat spreader 35. The lower heat spreader 35 is also made of aluminum, and is disposed below the thermal insulator 34 to maintain liquidity of the ink 32 in the ink feed chamber 28. The thermal insulator 34 may be made of any conventional thermally nonconductive material. The upper and lower heat spreaders 33, 35 and the thermal insulator 34 are fastened to the inner walls of the pen body 25 by a suitable adhesive, or by other mechanical means. A melt-on-demand heater 45 is disposed in intimate physical contact with ends of the upper heat spreader 33. A quick turn-on and delivery temperature control heater 44 (quick-on heater 44) is in intimate thermal contact with the lower heat spreader 35. The melt-on-demand heater 45 heats the ink 32 to a temperature above its melting point to allow it to flow into the ink feed chamber 28. The quick-on heater 44 heats ink in the ink feed chamber 28 to 10-40° C above its melting point to obtain the required low viscosity for ejection.

The use of phase-change ink typically requires two independent sources of heat: melt-on-demand and quick turn-on. Phase-change ink may deteriorate when exposed to excessive melt/freeze cycles or after prolonged storage in a liquid state. For this reason, it is desirable to melt only what is needed to replenish the liquid phase as fast as it is consumed by drop ejection. For example, a time average input of approximately five watts is required to heat solid ink from room temperature to delivery temperature with phase-change in a 50 nozzle print head ejecting 150 picoliter droplets at 4 KHz with a 50% duty-cycle.

Being able to bring the phase-change ink jet printer 10 on-line quickly from a cold start is an important advantage to a user. To accomplish this, the quick-on heater 44 is provided to melt ink located in the ink feed chamber 28. As will be clear hereinafter, a pressure regulator comprising a bubble generator 46, or bubble generator orifice 46, and the bladder 30 are use to keep the plenum chamber 26 maintained at a partial vacuum. It is advantageous to place the bubble generator 46 close to the quick-on heater 44. To reach operating temperature and to regulate pressure in 10 seconds starting from room temperature typically requires at least 33 watts per milliliter of melted ink. Typically, a temperature sensor 122 (Figs. 3 and 9) is disposed in the ink feed chamber 28 and connected in a temperature control loop shown in Fig. 9.

A flexible, and typically L-shaped, folded print engine 40 comprising a plastic substrate 41 is wrapped around one side and the bottom of the pen body 25. An adhesive (not shown) provides a structural attachment and seal between the print engine 40 and the pen body 25. The quick-on heater 44 and the melt-on-demand heater 45 are disposed on the inside surface of the plastic substrate 41 (adjacent the pen body 25) to accomplish both melt-on-demand and quick turn-on functions. The same materials and process steps used for unpassivated thermal ink jet heaters and conductors may be used for these heaters 44, 45.

A novel feature of the present invention is that means for providing thermal energy to melt phase-change ink on-demand and to provide quick turn-on is incorporated into the substrate 41 that forms the drop generator or print engine 40, thereby eliminating additional components and assembly steps in the fabrication of the thermal ink jet print cartridge 24.

The separate melt-on-demand heater 45 may be dispensed with, if desired, although it is ordinarily viewed as an essential element of the print cartridge 24. If desired, pen design may be simplified by feeding solid ink on-demand to the ink feed chamber 28 where ink in liquid phase is present. The liquid ink is delivered to the print engine 40 at a temperature significantly above its melting point (10-30° C) to control viscosity. The excess temperature above the melting point may be used to melt ink as required eliminating the separate melt-on-demand heater 45, but requiring the quick turn-on and delivery temperature control heater 44 to supply the heat of fusion.

When the melt-on-demand heater 45 is activated by supplying it electrical power, the upper heat spreader 33 becomes hot. As its temperature rises above the melting point of block of solid ink 32, phase change of the ink 32 occurs where it is in contact with the upper heat spreader 33. Liquidus then flows by gravity through holes 36, 37, 38 (shown more clearly in Fig. 3) in the upper heat spreader 33, the insulator 34, and the lower heat spreader 35, respectively. The liquidus enters delivery chamber 28 where its temperature is controlled by the quick-on heater 44 and the lower heat spreader 35.

The pen body 25 is provided with a large opening 43 in its side adjacent the melt-on-demand heater 45. The pen body 25 is provided with at least one small opening 42 to feed ink from the ink feed chamber 28 into the print engine 40. The flexible folded print engine 40 is a complete high-integration, monolithic thermal ink jet drop generator mechanism. The flexible folded print engine 40 is built up on the flexible substrate 41 that may be made of a plastic, such as polyimide, or the like. The bubble generator 46 in conjunction with the bladder 30 provides for regulation of the ink delivery pressure. The bubble generator 46 is formed by providing a laser-ablated orifice 46 (or set of orifices 46) in the plastic substrate 41. The orifice 46 is typically 150 to 250 microns in diameter, depending on the surface tension of the liquidus at delivery temperature. U.S. Patent Application Serial No. 07/868,355, filed April 2, 1992, entitled "Printhead and a Method for the Manufacture Thereof", assigned to the assignee of the present invention, discloses techniques for providing laser-ablated orifices.

The bubble generator 46 operates as follows. Measuring the pressure at which air begins to bubble into a liquid through an orifice 46 of known diameter is well-known in the art of measuring the surface tension of a liquid exposed to its vapor. This principle is employed in the present invention to regulate the ink delivery pressure. A meniscus in the bubble generator orifice 46 is drawn by subatmospheric pressure into the ink containment reservoir 27. The partial vacuum is created as ink is drawn from the reservoir 27 and ejected by the drop generator or print engine 40. Breakdown of the meniscus allows a bubble of air to enter the ink feed chamber 28. The additional volume of air thus introduced provides the means for pressure regulation since the time-average of air entering through the bubble generator 46 balances the volume of ink withdrawn for printing, thus maintaining the plenum chamber 26 at nearly constant pressure. The bubble generator 46 provides a source of air which makes up for volume ejected. The bubble generator 46 acts like a valve with a preset opening (or "cracking") pressure: it does not allow air to enter the plenum chamber 26 unless the plenum vacuum is sufficiently high to break down the meniscus.

The pressure at which the meniscus collapses and a bubble of air is ingested depends on the diameter of the bubble generator orifice 46, the surface tension of the liquid ink 32, and the wetting angle of the liquid ink 32 on the material comprising the bubble generator 46. For nominal values of surface tension and wetting angle, the regulation pressure is set by choice of the diameter of the bubble generator orifice 46. Smaller orifices 46 produce higher partial vacuums typically measured by the height (in inches) of a water column the vacuum can support. Decreasing the diameter of the orifice 46 increases the partial vacuum at which regulation occurs (by the bubbling of air into the ink feed chamber 28). For example, in an application to phase-changes inks with a surface tension of 24 dynes/cm, a 160 micron diameter orifice 46 regulates at 2.5 inch water column (measured at the plane of the bubble generator 46).

The present invention provides the novel feature of incorporating a pressure regulator integral with the substrate 41 that forms the drop generator or print engine 40, thereby eliminating additional components and assembly steps in the fabrication of the thermal ink jet print cartridge 24. Furthermore, this regulator employs a local heat source (the quick-on heater 44) for liquifying ink which has solidified in the ink chamber 28 so that air bubbles may enter the liquid phase, and means for removing the local heat source (turning the quick-on heater 44 off) to seal the bubble generator orifice 46 during handling and shipping, to preserve the partial vacuum within the pen body 25 and to prevent the discharge of ink.

The preferred embodiment incorporating bubble generators 46 in the plastic substrate 41 may be enhanced by a simple external dust shield (not shown) comprised of plastic or other suitable material. The location of the bubble generator 46 on an exposed, planar surface of a print cartridge 24 makes it susceptible to paper dust and other contamination affecting the wettability of the outer surface. This could affect pressure regulation, and in the worst case, allow ink to drool out of the bubble generator 46 and drop ejection orifices.

Because air in the plenum chamber 26 undergoes significant temperature changes as the heaters 44, 45 are activated, pressure regulation by the bubble generator 46 operates in association with the bladder 30. Air in the plenum chamber 26, which is at a partial vacuum of 1-4 inches of water regulated by the bubble generator 46, expands when heated by the melt-on-demand heater 45. At constant pressure, the volume of air in the plenum chamber 26 expands about one-third when heated from room temperature to 120° C. The bladder 30 has the stiffness necessary to maintain the partial vacuum 26 in the plenum chamber 26 and collapses by the amount the air expands, thus maintaining pressure nearly constant while allowing significant expansion of the trapped air in the plenum chamber 26. In the present invention, the volume change is due substantially to internally generated heat, and the volume swept out by bladder 30 is about 40% of the total volume of plenum chamber 26 to compensate for air expansion when solid block of ink 32 has been nearly consumed. The function of the bladder 30 may be provided by other suitable means, such as an elastomeric bladder or piston that employs a nearly constant preload.

Other inventors employed by the assignee of the present invention have devised flexible plastic substrates for structural elements of a thermal ink jet print head. The other inventors have variously integrated thin films, barriers, orifice plates, and electrical interconnects into the flexible plastic substrates. The present invention provides improvement over prior art thermal ink jet print head designs by integrating three additional functions therein: pressure regulation, ink filtration, and heaters for quick-turn on and melt-on-demand. Combined with the prior elements, these features enable fabrication of a complete thermal ink jet print engine 40 on a plastic substrate 41 except for the ink containment, mechanical alignment, heat transfer, and volume compensation components.

Fig. 3 is an exploded partially cutaway view of the print cartridge 24 made in accordance with the principles of the present invention. Fig. 3 illustrates how the cartridge 24 is assembled and the relative locations and relationships of its components. In particular, Fig. 3 shows how the melt-on-demand heater 45 contacts the outer ends of the upper heat spreader 33 and how the quick- on heater 44 contacts the under side of the lower heat spreader 35. Thus a thermal path is made between respective ones of the heaters 44, 45 to corresponding ones of the heat spreaders 33, 35. The holes 36, 37, 38 and the ink feed chamber

28 are shown more clearly, which illustrates the path that the liquified ink 32 takes on its way to the print engine 40.

Fig. 4 shows one embodiment of the high-integration monolithic print engine 40 of the present invention. Fig. 4 is a plan view of the front side of the substrate 41 prior to folding. The substrate 41 is made of a plastic, such as polyimide, for example, which has high tensile strength, dimensional stability, and chemical inertness to the ink. A fold line 50 is formed by laser ablation of perforations, and the portion of the substrate 41 to the right of the fold line 50 defines an orifice plate 51. A plurality of drop ejection chambers 52 are formed by laser ablation to a depth of about half the thickness of the substrate 41. The drop ejection chambers 52 are separated from each other by unablated portions of the substrate 41 that define integral ink barriers. Each of the drop ejection chambers 52 is provided with a nozzle 53 that is ablated completely through the substrate 41. These nozzles 53 are of a predetermined diameter and eject drops of liquid ink 39 from the cartridge 24 onto the paper 15. Five chambers 52 and nozzles 53 are illustrated in Fig. 4 for convenience, but the number may be typically on the order of several hundred in actual practice. Without affecting the primary features of this invention, the drop ejection chambers 52 may be formed photolithographically in a thick film material, such as a solder mask material that is laminated onto the substrate 41, and the orifice plate 51.

To the left of the fold line 50 there are provided a plurality of vaporization heaters 54 for vaporizing the ink in the drop ejection chambers 52. The vaporization heaters 54 may be formed by well-known thin film or thick film processes. It will be understood that after the orifice plate 51 is folded at the fold line 50, the drop ejection chambers 52 are superimposed over the heaters 54. The small openings 42 that feed ink 32 from the ink feed chamber 28 to the drop ejection chambers 52 are located near the vaporization heaters 54. A plurality of conductive traces 55 that define a flexible circuit each individually connect the vaporization heaters 54 to electrical interconnect terminals 56 disposed at the left end of the substrate 41. A common return circuit trace 64 connects all or a group of the vaporization heaters 54 to a common return circuit terminal 65. The bubble generator orifices 46 are ablated completely through the substrate 41 near the vaporization heaters 54.

Fig. 5 is a plan view of the back side of the substrate 41. It will be understood that after the print engine 40 is folded around one side and the bottom of the pen body 25 as shown in Fig. 2, the back side of the substrate 41 as shown in Fig. 5 is on the inside of the print cartridge 24. In Fig. 5, a first dashed line lies along the fold line 50 that defines the orifice plate 51. A second dashed line 59 defines the L-fold line that separates the side 57 of the substrate 41 from the bottom 58. The nozzles 53 can be seen in the orifice plate 51, and the ablated ink feed openings 42 can be seen nearby in the bottom 58 of the substrate 41. The bubble generator orifices 46 may be seen in the bottom 58 of the substrate 41. The quick turn-on and delivery temperature control heater 44 is disposed on the bottom 58 of the substrate 41 and has a conductive trace 60 that extends to a via 61b. The melt-on-demand heater 45 is disposed on the side 57 of the substrate 41 and has a separate conductive trace 62 that extends to a via 63b. A common return circuit trace 66 connects the quick-on heater 44 and the melt-on-demand heater 45 to a common return circuit via 67b.

Fig. 6 is a perspective view of the print engine 40 folded into its L-shape. In this view, the drop generator has been formed by folding the orifice plate 51 along the first and second fold line 50, 59 to overlay the drop ejection chambers 52 on the vaporization heaters 54.

The quick-on heater 44 and the melt-on-demand heater 45 may be thin-film heaters formed by a metal layer on the back side of the substrate 41 shown in Fig. 5 or, alternatively, they may be formed by laminating a second plastic film that already has the heaters 44, 45 in place onto the substrate 41. There exist several options for design of the quick turn-on and delivery temperature control heater 44 and the melt-on-demand heater 45. The heaters 44, 45 may comprise a thin film resistor typically comprising 0.5 to 3 squares of resistor material with conductors at each end. Another embodiment employs the same arrangement with openings in the resistor material. This provides electrical isolation between the heater and jumpers connecting front-side conductors by plated-through holes. Current crowding around these features produces nonuniform heating. This may either be ignored or the effect minimized by the spatial arrangement of the vias. Another embodiment provides an arrangement of resistive strips between the edge conductors. The space between the strips are used to electrically isolate the heaters 44, 45 from jumpers between front-side conductors. This arrangement may also be used to provide a higher number of squares of the resistive material to adjust the overall heater resistance.

There exists further options for the quick turn-on and delivery temperature control heater 44. The bubble generator 46 may be placed within the quick turn-on and delivery temperature control heater 44 to satisfy the need to melt ink rapidly over the bubble generator 46 and in the ink feed chamber 28 between the print engine 40 and the plenum chamber 26. The heater material may be directly exposed to phase-change ink 32 for efficient heat transfer without the thermal resistance of an intervening layer. Optionally, removal of heater material may be required to control the wetting angle in the vicinity of the bubble generator

46. Another embodiment forms the quick turn-on and delivery temperature control heater 44 from a thick film which may be deposited by silk-screen printing or other suitable means. This quick-on heater 44 makes electrical connection to conductors 60, 66, and 62 as does the thin-film quick turn-on and delivery temperature control heater 44 described previously.

Another embodiment forms the heaters 44, 45 on a separate plastic substrate using different processes from those used for the thin-film heaters 44, 45 and conductors on the front-side as shown in Fig. 4. These heaters 44, 45 and conductors do not require the lithographic precision of the front side metallization, and there may be a cost advantage to separating the back side heater and conductor processes from the steps used in folded substrate 41 of the present invention. The plastic substrate containing the heaters 44, 45 and conductors 60, 66, 62 may then be laminated onto the substrate containing the vaporization heaters 54, drop ejection chambers 52, orifices 46, etc. A window opening in the second film and heater in the manner described above allows the bubble generator 46 to be defined on the outer plastic layer by laser-ablation processes and to bubble through the laminated layer. The laminated heater makes electrical connection to conductors 60, 62, and 66 as previously described. Connection may be by soldering, conductive epoxy, or other suitable means.

Conventional thermal ink jet print cartridges employ an ink filter composed of a woven wire mesh. Typically, this mesh is chosen to reject particles greater than 10-20 microns in diameter to prevent clogging of the drop ejection orifices. The present invention uses laser-ablation to form an array of filter holes 70 in the plastic substrate 41, as shown in Fig. 7. This is done simultaneously with ablation of other architectural features, including the drop ejection chambers 52, the firing nozzles 53, and the bubble generator orifices 46.

Fig. 7 is an enlarged broken away view of a fragment of the substrate 41. It shows a detail of the integral ink filter formed by an array of filter holes 70, each typically in the range 10-20 microns in diameter. A footprint 71 of the drop ejection chamber 52 after folding may be seen as a dotted line surrounding the array of filter holes 70 and the vaporization heater 54. Although round holes 70 are shown, other configurations may be useful: obround, oval, and slots. A sufficient number of holes 70 is required so that the flow impedance through the integral filter remains within acceptable limits as some holes 70 become clogged. The number, diameter, and shape of the holes 70 may be chosen to obtain a nominal refill impedance for fluidic tuning of the drop ejection chamber 52. It is to be understood that these filter holes 70 are used in place of the small ink feed openings 42 shown in Figs. 2, 4 and 5. Also, it should be understood that the array of filter holes 70 may be used in liquid ink pens as well as phase-change ink pens. Thus additional novelty in the present invention resides in an ink filtration system that is integral with the substrate 41, and which forms the drop generator 40, thereby eliminating additional components and assembly steps in the fabrication of the thermal ink jet print cartridge 24.

Referring now to Fig. 8a, there is shown a broken away cross sectional view of the drop generator 40. An ink reservoir 91 has walls 92 containing liquid ink 32 in which are solid particles 93. A folded portion 94 of the substrate 41 has the array of filter holes 70 separating the liquid ink 32 from the drop ejection chamber 52 and ejection nozzle 97. In operation, the array of filter holes 70 prevents the solid particles 93 from entering the drop ejection chamber 52. Liquid ink 32 may also be the liquidus of phase-change ink. Referring now to Fig. 8b, there is shown a cross-sectional view of the drop generator 40 of Fig. 8a. The folded portion 94 of the substrate 41 is provided with the filter holes 70 that lead into a drop ejection chamber 52. As seen in Fig. 8b, one wall of the drop ejection chamber 52 which comprises the substrate 41 has a vaporization heater 98, and the opposite wall is provided with the ejection nozzle 97.

Referring now to Fig. 9, there is shown a schematic diagram of a control system 110 for regulating temperature and ink level in a thermal ink jet print cartridge 24. The solid block of phase change ink 32 is contained in the ink containment reservoir 27, and liquid ink 115 is present in the ink feed chamber 28. The solid block of phase change ink 32 rests upon the upper heat spreader 33. The melt-on-demand heater 45 is shown schematically by a resistor and is connected to a melt-on-demand and ink level regulator 120 which obtains power by being connected to a power supply 121. An ink level sensor 122 is provided in the wall of the pen body 25 in the vicinity of the ink feed chamber 28, to maintain an appropriate level of liquidus for delivery to the print engine 40. The ink level sensor 122 is electrically connected to the ink level regulator 120 and this combination controls the amount of heating produced by the melt-on-demand heater 45. The ink level regulator 120 compares the signal from the ink level sensor 122 to a preset value representing a nominal ink level. When a signal representing less than nominal ink level in the ink feed chamber 28 is received, power is applied to the melt-on-demand heater 45 causing solid ink 32 to melt. The liquidus entering the ink feed chamber 28 raises the level of ink, and power is removed from the melt-on-demand heater 45 when the ink level sensor 122 indicates a level at or above nominal. The ink level sensor 122 may employ any of a number of means known in the art. This includes a thermistor operated in a self-heating mode whereby the presence of the liquidus absorbs heat from the device thus lowering its temperature below that observed in the absence of the liquidus.

The quick turn-on and delivery temperature control heater 44 is shown schematically as a resistor and is integrated into the print engine 40 and is electrically connected to a delivery temperature regulator 124. The delivery temperature regulator 124 also draws power from the power supply 121. A temperature sensor 125 is disposed in the ink feed chamber 28 where it can monitor the temperature of the liquid ink 32. The temperature sensor 125 is electrically connected to the delivery temperature regulator 124 and this combination controls the amount of heating produced by the quick turn-on and delivery temperature control heater 44. The regulator 124 compares the temperature-related signal from the temperature sensor 125 to an internal preset reference. Power is applied to the quick-on heater 44 whenever the temperature sensed by the temperature sensor 125 is less than the preset value. Temperature sensing means well-known in the art such as thermistors, thermocouples, and temperature-sensing resistors may be employed as the temperature sensor 125. For both the ink level regulator 120 and the delivery temperature regulator 124, simple control algorithms employing proportional, integral, and differential compensation, or any combination thereof may be used.

Referring now to Fig. 10, there is shown a schematic diagram of a second control system 110a in accordance with the present invention for regulating temperature and ink level in a thermal ink jet print cartridge 24a. This embodiment is substantially the same as the embodiment of Fig. 2, except that the melt-on-demand heater 45 and the integrated monolithic print engine 40 have been modified, identified as print engine 40a. The solid block of phase change ink 32 is contained in the ink containment reservoir 27, and liquid ink 115 is present in the ink feed chamber 28. The solid block of phase change ink 32 rests upon the upper heat spreader 33. A melt-on-demand heater 45a is shown schematically by a resistor that is part of the upper heat spreader 33 and is connected to the melt-on-demand and ink level regulator 120 which obtains power from the power supply 121. In this embodiment, the melt-on-demand heater 45a replaces the melt-on-demand heater 45 described above. The ink level sensor 122 is provided in the wall of the pen body 25 in the vicinity of the ink feed chamber 28, to maintain an appropriate level of liquidus for delivery to print engine 40. The ink level sensor 122 is electrically connected to the ink level regulator 120 and this combination controls the amount of heating produced by the melt-on-demand heater 45a. The ink level regulator 120 compares the signal from the ink level sensor 122 to a preset value representing a nominal ink level. When a signal representing less than nominal ink level in the ink feed chamber 28 is received, power is applied to the melt-on-demand heater 45a causing solid ink 32 to melt. The liquidus entering the ink feed chamber 28 raises the level of ink, and power is removed from the melt-on-demand heater 45a when the ink level sensor 122 indicates a level at or above nominal.

Fig. 11 illustrates the integrated monolithic print engine 40a employed in the print cartridge 24a of Fig. 10. This print engine 40a is substantially the same as the print engine 40 described with reference to Figs. 4-6, except that the alternative melt-on-demand heater 45a is formed as part thereof. Only some of the details of the print engine 40a are referenced, due to their similarity to the print engine 40 previously described. The melt-on-demand heater 45a may be formed as an L-shaped member in the manner as described above and wherein the melt-on-demand heater 45a is formed thereon as a thin film, for example, and has an opening 130 disposed therein that permits liquid ink 115 to flow into the ink feed chamber 28. The L-shaped member having the melt-on-demand heater 45a formed thereon may be attached to the vertical wall of the print engine 40a in a conventional manner using adhesive, or by soldering together metalized regions, for example.

As a further modification of the integrated monolithic print engine 40a described above, the print engine 40a may incorporate a printed circuit board 41a in lieu of the plastic substrate 41 described previously. The printed circuit board 41a comprises the vertical portion of the print engine 40a as it is shown in Fig. 11. The lower L-shaped portion of the print engine 40a comprising the quick turn-on and delivery temperature control heater 44 may be bonded to the printed circuit board 41a by means of conductive epoxy, or other adhesive, or may be reflow soldered, for example. Similarly, the upper L-shaped portion of the print engine 40a comprising the melt-on-demand heater 45a may also be bonded to the printed circuit board 41a by means of the conductive epoxy or may be reflow soldered, for example. The electrical connections for power to the heaters 44, 45a may also be provided by conductive epoxy, or reflow soldering, for example. Those skilled in the art may easily couple the heaters 44, 45a to the printed circuit board 41a using well-known printed circuit wiring techniques.

The above-described modification to the print engine 40a is quite desirable, since this modification substitutes relatively inexpensive printed circuit material for relatively expensive flexible circuit material in the vertical portion of the print engine 40a. From a manufacturing cost standpoint, this modified design provides a cost-effective approach for the integrated monolithic print engine 40a.

Thus, there has been described new and improved integrated monolithic thermal ink jet print heads that incorporates pressure regulation, ink filtration, melt-on-demand, and quick turn-on heaters. Several substrates may be employed on which the heaters are disposed. The features disclosed are useful with solid phase change ink print heads, although the array of filter holes is also useful with liquid ink print cartridges. It is a feature of the invention that it employs a local heat source for liquifying solid ink so that air bubbles from a bubble generator pressure regulator may enter the liquid phase, and removing the local heat source to seal the bubble generator orifice during handling and shipping to preserve a partial vacuum within the regulator and prevent discharge of ink. Another feature is that expansion of air in the plenum chamber due to internally generated heat is compensated for by bellows vented to the outside. It is to be understood that the above-described embodiments are merely illustrative of some of the many specific embodiments that represent applications of the principles of the present invention. Clearly, numerous and other arrangements can be readily devised by those skilled in the art without departing from the scope of the invention.

Claims

1. In a thermal ink jet print head comprised of an enclosure (26) forming a plenum chamber (26), a substrate (41) having features defining a liquid ink ejection chamber (52) attached to the enclosure, an orifice plate (51) having drop ejection orifices (53) disposed therein formed in the substrate (41), a plurality of heating elements (54) disposed on the substrate (41) for vaporizing phase-change ink (32) to provide a bubble for ejecting ink droplets through the orifices (53), and electrical conductors (55) disposed on the substrate (41) for coupling heating current to the plurality of heating elements (54), wherein the improvement is characterized by:

   pressure regulating means (46, 30) including a flexible member (30) disposed in the enclosure (26) that is adapted to change its volume as a function of the volume of phase-change ink (32) disposed therein and the temperature of the enclosure (26), and including an orifice (31) that vents the interior of the flexible member (30) to atmospheric pressure in order to substantially maintain a subatmospheric pressure within the enclosure (26), and a bubble generator (46) disposed in the flexible substrate (41) that comprises at least one orifice having a predetermined diameter that is adapted to cooperate with the pressure regulating means to regulate pressure within the enclosure (26).

2. The thermal ink jet print head of Claim 1 wherein the improvement is further characterized by:

   an ink filter (70) comprising an array of openings disposed in the substrate (41) between the plenum chamber (26) and the liquid ink ejection chamber (52), and wherein the size of the openings is chosen to prevent passage of particles from the plenum chamber (26) into the liquid ink ejection chamber (52) that are larger than a predetermined size.

3. The thermal ink jet print head of Claim 2 wherein the improvement is further characterized by:

   a heat spreading member (33) disposed within the enclosure (26) that is in contact with the phase-change ink (32) disposed within the enclosure (26); and

   a quick-on and temperature regulating heater (44) disposed in contact with the heat spreading member (33) in close proximity to the liquid ink ejection chamber (52) that is adapted to heat the phase-change ink (32) to a temperature above its melting point to obtain a desired viscosity that is suitable for ejection, and rapidly heat the phase-change ink (32) to a predetermined ejection temperature prior to its ejection from the print head, and provide melt-on-demand, quick-on and temperature regulating heating of the phase-change ink (32).

4. The thermal ink jet print head of Claim 3 wherein the improvement is further characterized by:

   a melt-on-demand heater (45) disposed on a surface of the substrate (41) adjacent the interior of the enclosure (26), which is disposed in contact with the the heat spreading member (33) and is adapted to heat the phase-change ink (32) to a temperature above its melting point to allow the ink (32) to flow to the drop ejection chambers (52).

5. The thermal ink jet print head of Claim 1 wherein the improvement is further characterized by:

   a heat spreading member (33) disposed within the enclosure (26) that is in contact with the phase-change ink (32) disposed within the enclosure (26); and

   a quick-on and temperature regulating heater (44) disposed in contact with the heat spreading member (33) in close proximity to the liquid ink ejection chamber (52) that is adapted to heat the phase-change ink (32) to a temperature above its melting point to obtain a desired viscosity that is suitable for ejection, and rapidly heat the phase-change ink (32) to a predetermined ejection temperature prior to its ejection from the print head, and provide melt-on-demand, quick-on and temperature regulating heating of the phase-change ink (32).

6. The thermal ink jet print head of Claim 5 wherein the improvement is further characterized by:

   a melt-on-demand heater (45) disposed on a surface of the substrate (41) adjacent the interior of the enclosure (26), which is disposed in contact with the the heat spreading member (33) and is adapted to heat the phase-change ink (32) to a temperature above its melting point to allow the ink (32) to flow to the drop ejection chambers (52).

7. The thermal ink jet print head of Claim 1 wherein the improvement is further characterized by:

a heat spreading member (33) disposed within the enclosure (26) that is in contact with the phase-change ink (32) disposed within the enclosure (26); and

a plurality of heaters (44, 45) disposed on a surface of the substrate (41) adjacent the interior of the enclosure (26), which plurality of heaters comprises a melt-on-demand heater (45) and a quick-on and temperature regulating heater (44), wherein the melt-on-demand heater (45) is disposed in contact with the the heat spreading member (33) and is adapted to heat the phase-change ink (32) to a temperature above its melting point to allow it to flow to the drop ejection chambers, wherein the quick-on and temperature regulating heater (44) is disposed in contact with the the heat spreading member (33) in close proximity to the liquid ink ejection chamber (52) and is adapted to rapidly heat the phase-change ink (32) to a predetermined ejection temperature to obtain a desired viscosity that is suitable for ejection prior to its ejection from the print head, the plurality of heaters (44, 45) thus providing melt-on-demand, quick-on and temperature regulating heating of the phase-change ink (32).

8. The thermal ink jet print head of Claim 1 wherein the improvement is further characterized by a second melt-on-demand heater (45a) coupled to the heat spreader (33) adjacent the phase-change ink (32).

9. The thermal ink jet print head of Claim 1 wherein the the improvement is further characterized by a flexible substrate (41) physically and electrically coupled to a printed circuit board that comprises the melt-on-demand heater (45).

10. The thermal ink jet print head of Claim 1 wherein the improvement is further characterized by a printed circuit board to which the melt-on demand heater (45) is physically and electrically attached, and a flexible substrate (41) physically and electrically coupled to a printed circuit board that comprises the quick turn-on and delivery temperature control heater (44).

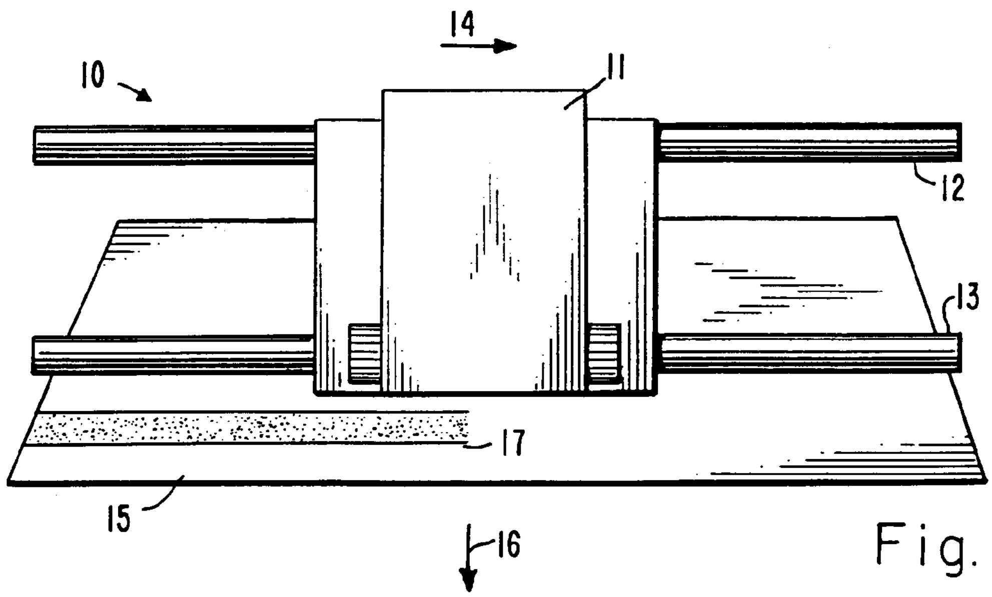
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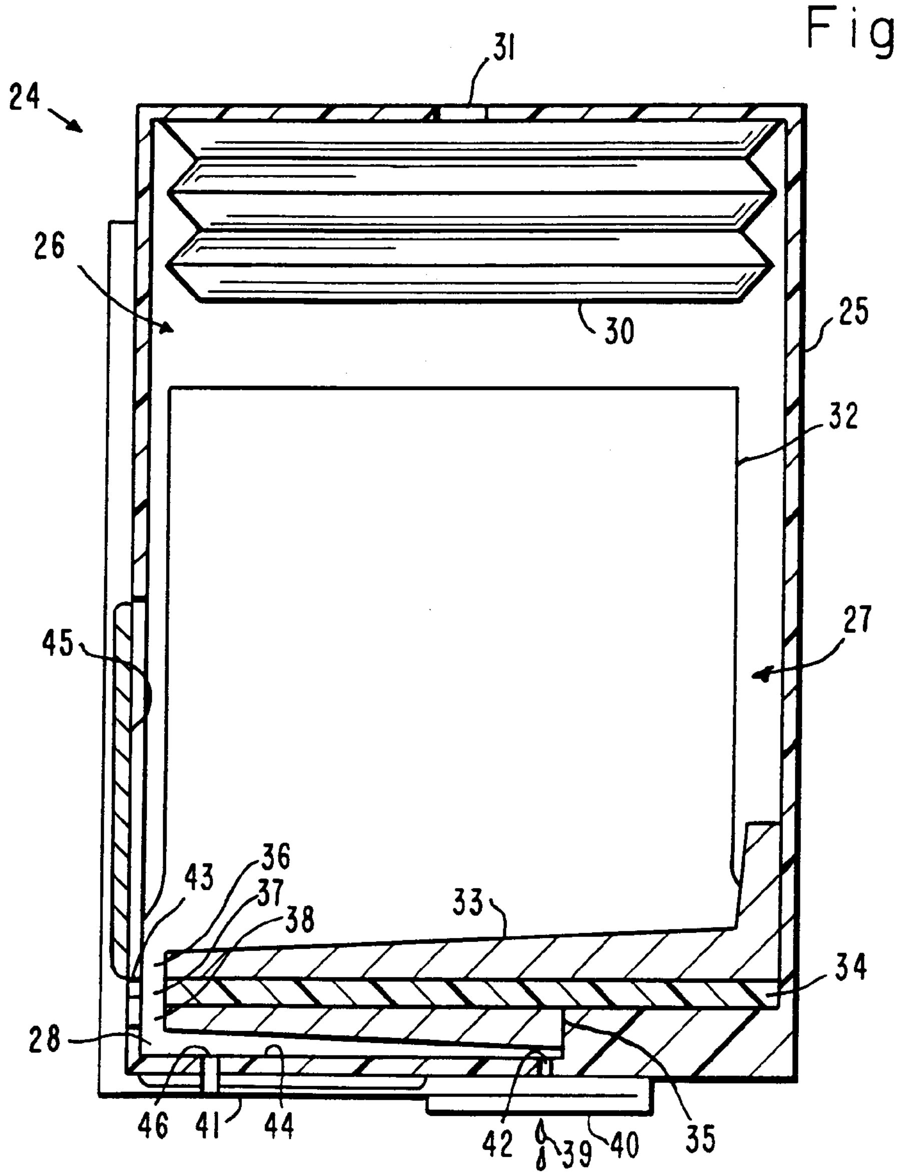
Fig. 1.

Fig. 2.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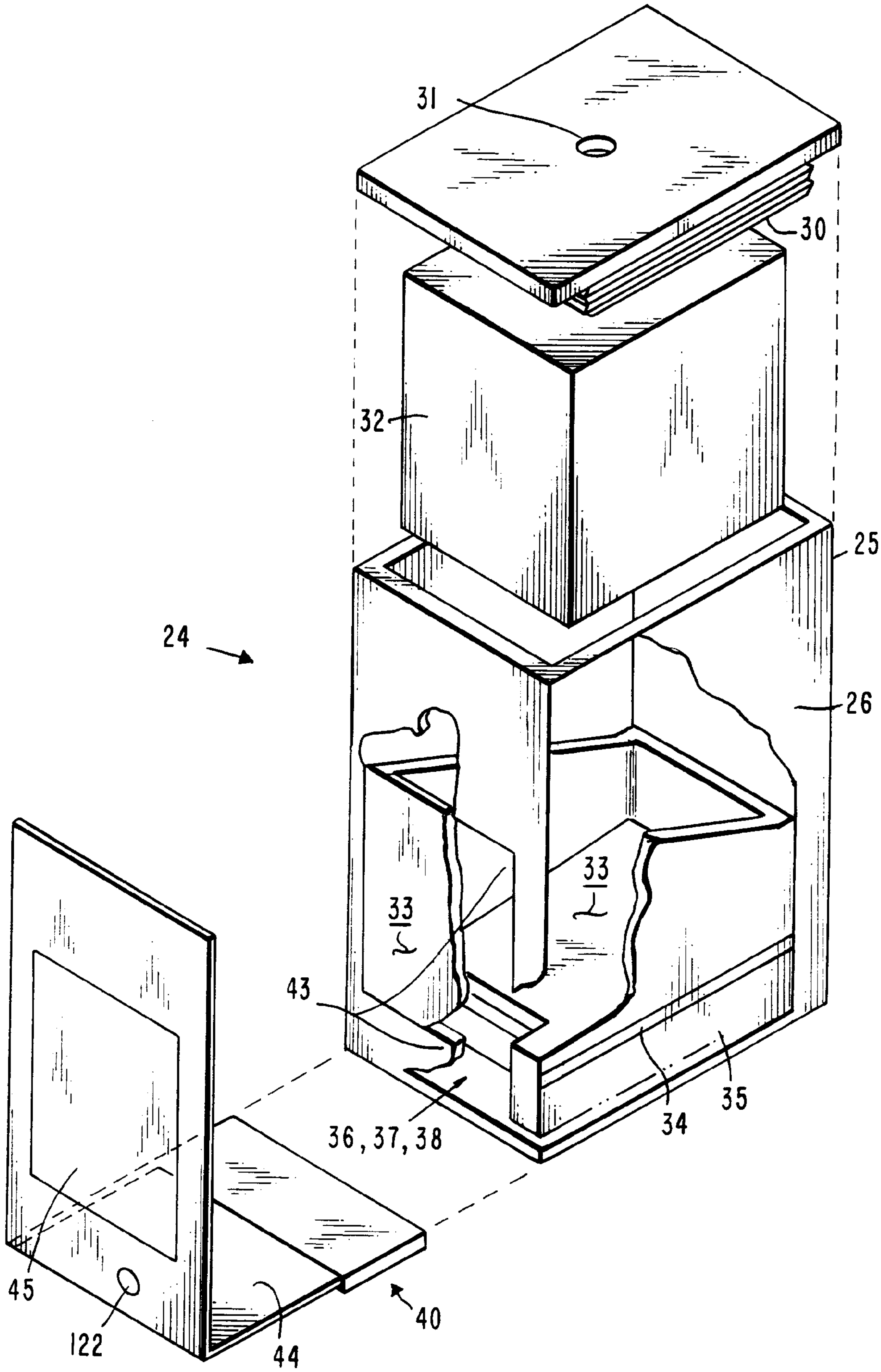


Fig. 3.

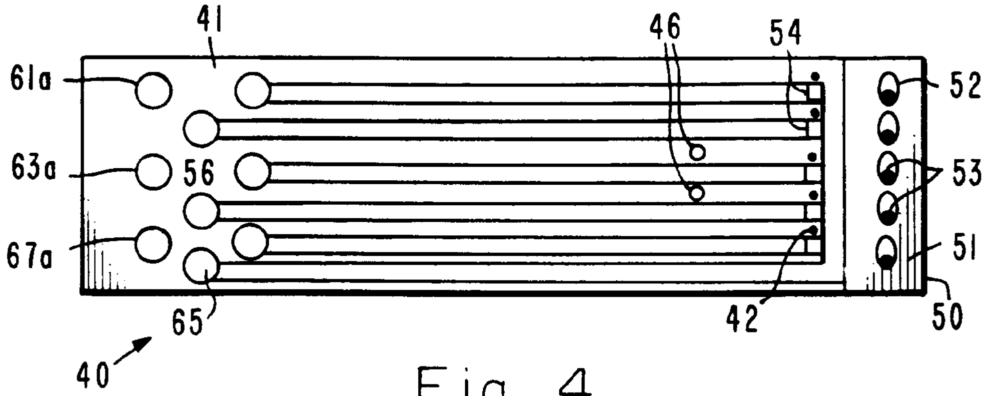


Fig. 4.

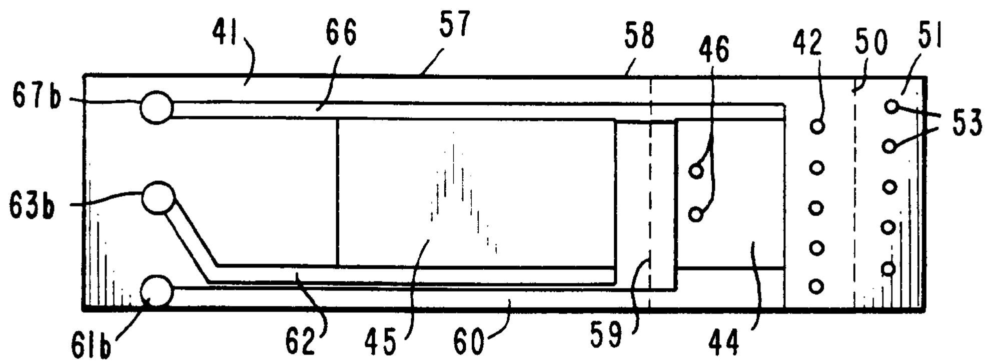
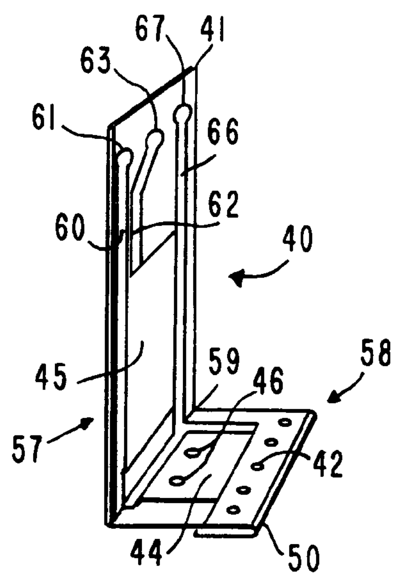


Fig. 5.

Fig. 6.



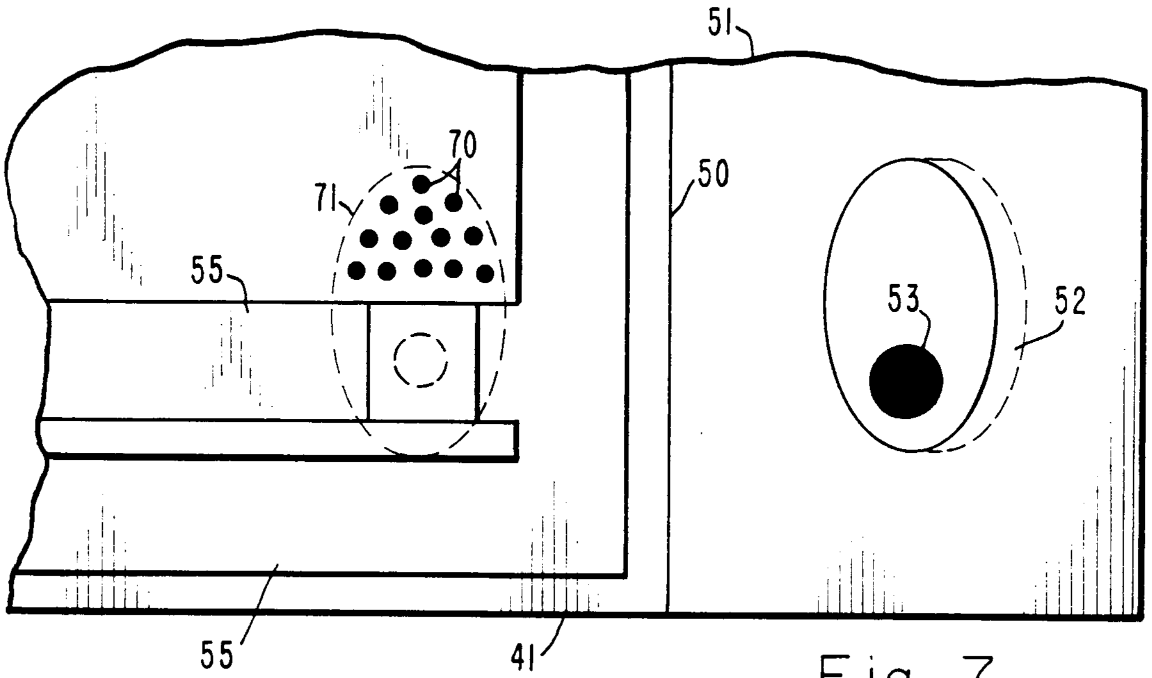


Fig. 7

Fig. 8a.

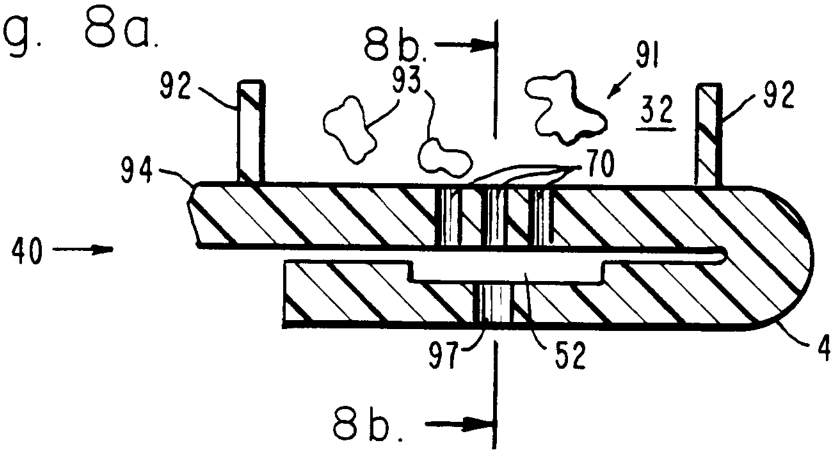
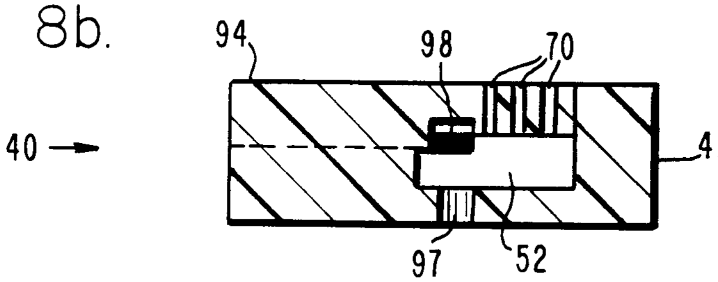
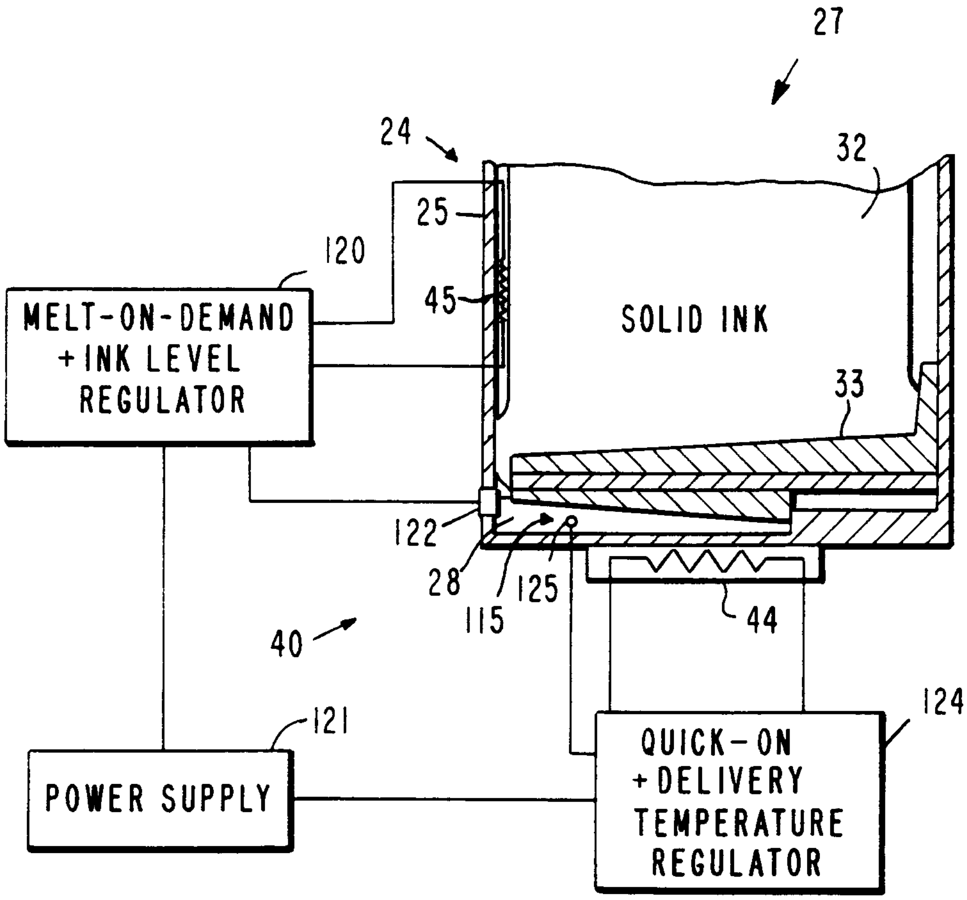


Fig. 8b.

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SOLID INK
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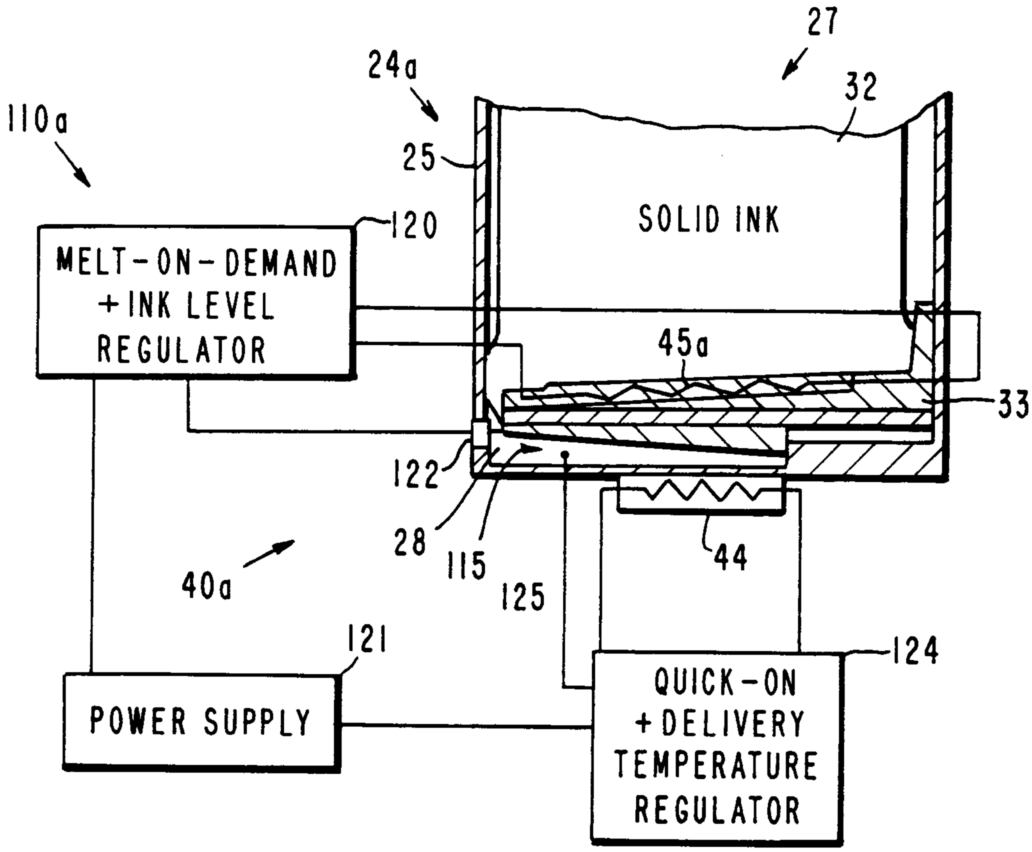
125
44
40
121
124
POWER SUPPLY
QUICK-ON
+ DELIVERY
TEMPERATURE
REGULATOR

Fig. 9.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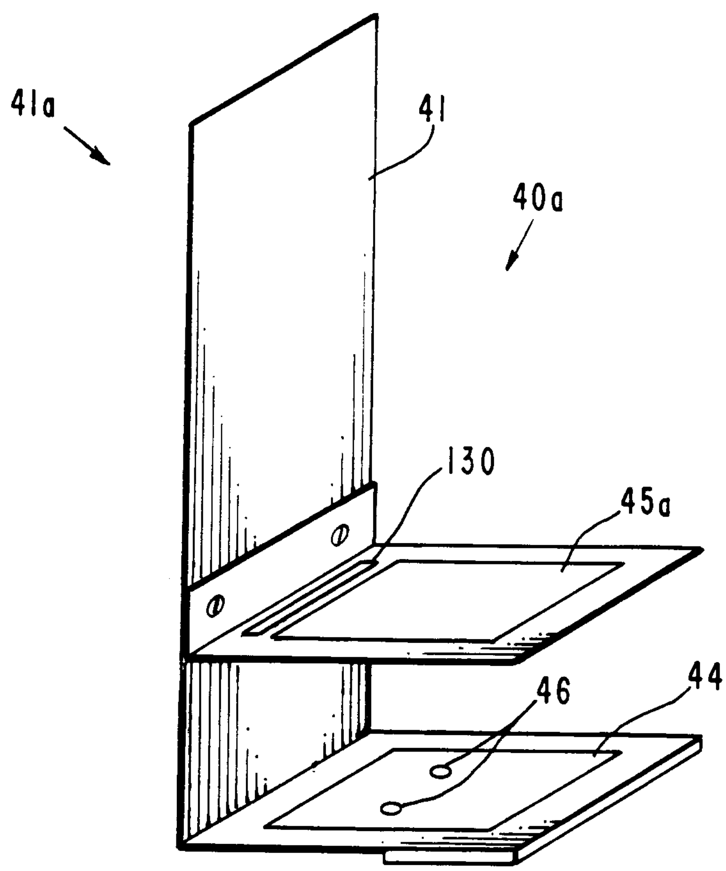
125
121
124
POWER SUPPLY
QUICK-ON
+DELIVERY
TEMPERATURE
REGULATOR

Fig. 10.


41a
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45a
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44

Fig. 11.