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(54) Continuous ink jet printer with electrostatic drop deflection

(57) Apparatus and process for controlling ink in a continuous ink jet printer in which a continuous stream (60) of ink is emitted from a nozzle includes an ink stream generator (50) which establishes a continuous flow of ink in a stream, the stream breaking up into a plurality of droplets (67) at a position spaced from the ink stream generator. A stream deflector adjacent to the stream between the ink stream generator and the position whereat the stream breaks up into droplets controls the direction of the stream between a print direction and a non-print direction. The apparatus may further include charging apparatus associated with the ink delivery channel to electrically charge the ink stream. The stream deflector includes at least one deflection electrode (65) and a deflection control circuit (13) adapted to selectively apply to the deflection electrode an electrical potential of a potential to deflect droplets from one of the print and non-print directions to the other of the print and non-print directions.

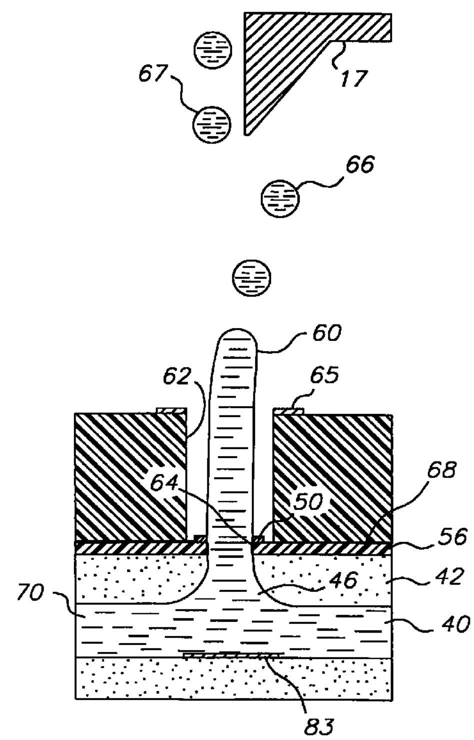

FIG. 2A

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Description

FIELD OF THE INVENTION

[0001] This invention relates generally to the field of digitally controlled printing devices, and in particular to continuous ink jet printheads which integrate multiple nozzles on a single substrate and in which the breakup of a liquid ink stream into droplets is caused by a periodic disturbance of the liquid ink stream.

BACKGROUND OF THE INVENTION

[0002] Many different types of digitally controlled printing systems have been invented, and many types are currently in production. These printing systems use a variety of actuation mechanisms, a variety of marking materials, and a variety of recording media. Examples of digital printing systems in current use include: laser electrophotographic printers; LED electrophotographic printers; dot matrix impact printers; thermal paper printers; film recorders; thermal wax printers; dye diffusion thermal transfer printers; and ink jet printers. However, at present, such electronic printing systems have not significantly replaced mechanical printing presses, even though this conventional method requires very expensive setup and is seldom commercially viable unless a few thousand copies of a particular page are to be printed. Thus, there is a need for improved digitally controlled printing systems, for example, being able to produce high quality color images at a high-speed and low cost, using standard paper.

[0003] Ink jet printing has become recognized as a prominent contender in the digitally controlled, electronic printing arena because, e.g., of its non-impact, low-noise characteristics, its use of plain paper and its avoidance of toner transfers and fixing. Ink jet printing mechanisms can be categorized as either continuous ink jet or drop on demand ink jet. Continuous ink jet printing dates back to at least 1929. See U.S. Patent No. 1,941,001 to Hansell.

[0004] U.S. Patent No. 3,373,437, which issued to Sweet et al. in 1967, discloses an array of continuous ink jet nozzles wherein ink drops to be printed are selectively charged and deflected towards the recording medium. This technique is known as binary deflection continuous ink jet, and is used by several manufacturers, including Elmjet and Scitex.

[0005] U.S. Patent No. 3,416,153, which issued to Hertz et al. in 1966, discloses a method of achieving variable optical density of printed spots in continuous ink jet printing using the electrostatic dispersion of a charged drop stream to modulate the number of droplets which pass through a small aperture. This technique is used in ink jet printers manufactured by Iris.

[0006] U.S. Patent No. 3,878,519, which issued to Eaton in 1974, discloses a method and apparatus for synchronizing droplet formation in a liquid stream using electrostatic deflection by a charging tunnel and deflection plates.

[0007] US Patent No. 4,346,387, which issued to Hertz in 1982 discloses a method and apparatus for controlling the electric charge on droplets formed by the breaking up of a pressurized liquid stream at a drop formation point located within the electric field having an electric potential gradient. Drop formation is effected at a point in the field corresponding to the desired predetermined charge to be placed on the droplets at the point of their formation. In addition to charging tunnels, deflection plates are used to actually deflect drops.

[0008] Conventional continuous ink jet utilizes electrostatic charging tunnels that are placed close to the point where the drops are formed in a stream. In this manner individual drops may be charged. The charged drops may be deflected downstream by the presence of deflector plates that have a large potential difference between them. A gutter (sometimes referred to as a "catcher") may be used to intercept the charged drops, while the uncharged drops are free to strike the recording medium. If there is no electric field present or if the drop break off point is sufficiently far from the electric field (even if a portion of the stream before drop break off is in the presence of an electric field), then charging will not occur. In the current invention, the electrostatic charging tunnels are unnecessary.

DISCLOSURE OF THE INVENTION

[0009] It is an object of the present invention to provide a high speed apparatus and method of page width printing utilizing a continuous ink jet method whereby drop formation and deflection may occur at high repetition.

[0010] It is another object of the present invention to provide an apparatus and method of continuous ink jet printing with drop deflection means which can be integrated with the printhead utilizing the advantages of silicon processing technology offering low cost, high volume methods of manufacture.

[0011] It is yet another object of the present invention to provide an apparatus and method of high speed printing that can use a wide variety of inks.

[0012] It is still another object of the present invention to provide an apparatus and method for continuous ink jet printing that does not require electrostatic charging tunnels.

[0013] According to one feature of the present invention, apparatus for controlling ink in a continuous ink jet printer in which a continuous stream of ink is emitted from a nozzle includes an ink stream generator which establishes a continuous flow of ink in a stream, the stream breaking up into a plurality of droplets at a position spaced from the ink stream generator. A stream deflector adjacent to the stream between the ink stream generator and the position whereat the stream breaks up into droplets controls the direction of the stream between a print direction and a non-print direction.

[0014] According to yet another feature of the present invention, the apparatus further includes deflection apparatus associated with the ink delivery channel to deflect the ink stream. The stream deflector includes at least one deflection electrode and a deflection circuit adapted to selectively apply to the deflection electrode an electrical potential to deflect droplets from one of the print and non-print directions to the other of the print and non-print directions.

[0015] According to a preferred embodiment of the present invention, the ink stream generator includes an ink delivery channel, a source of ink communicating with the ink delivery channel, wherein the ink is pressurized above atmospheric pressure, and a nozzle bore opening into the ink delivery channel. The droplet generator is a heater adjacent to the nozzle bore. An ink gutter is positioned in the path of ink droplets traveling in only one of said print and non-print directions.

[0016] The invention, and its objects and advantages, will become more apparent in the detailed description of the preferred embodiments presented below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] In the detailed description of the preferred embodiments of the invention presented below, reference is made to the accompanying drawings, in which:

Figure 1 shows a simplified block schematic diagram of one exemplary printing apparatus according to the present invention.

Figure 2(a) shows a cross section of the nozzle with electrostatic deflection means.

Figure 2(b) shows a top view of nozzle with electrostatic deflection means.

Figure 3(a) is an image, obtained experimentally, of the electrostatic deflection means with no potential applied.

Figure 3(b) is an image, obtained experimentally, of the electrostatic deflection means with potential applied.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The present description will be directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with the present invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

[0019] Referring to Figure 1, a continuous ink jet printer system includes an image source 10 such as a scanner or computer which provides raster image data, outline image data in the form of a page description language, or other forms of digital image data. This image data is converted to half-toned bitmap image data by an image processing unit 12 which also stores the image data in memory. A plurality of drop deflection control circuits 13 read data from the image memory and apply time-varying electrical pulses to a drop deflection means 15. Time-varying electrical pulses are supplied to a plurality of heater control circuits 14 that supply electrical energy to a set of nozzle heaters 50, Figure 2(a), that are part of a printhead 16. These pulses are applied at an appropriate time, and to the appropriate nozzle, so that drops formed from a continuous ink jet stream will form spots on a recording medium 18 in the appropriate position designated by the data in the image memory.

[0020] Recording medium 18 is moved relative to printhead 16 by a recording medium transport system 20, and which is electronically controlled by a recording medium transport control system 22, which in turn is controlled by a micro-controller 24. The recording medium transport system shown in Figure 1 is a schematic only, and many different mechanical configurations are possible. For example, a transfer roller could be used as recording medium transport system 20 to facilitate transfer of the ink drops to recording medium 18. Such transfer roller technology is well known in the art. In the case of page width printheads, it is most convenient to move recording medium 18 past a stationary printhead. However, in the case of scanning print systems, it is usually most convenient to move the printhead along one axis (the sub-scanning direction) and the recording medium along the orthogonal axis (the main scanning direction) in a relative raster motion.

[0021] Micro-controller 24 may also control an ink pressure regulator 26, drop deflection control circuits 13, and heater control circuits 14. Ink is contained in an ink reservoir 28 under pressure. In the non-printing state, continuous ink jet drop streams are unable to reach recording medium 18 due to an ink gutter 17 that blocks the stream and which may allow a portion of the ink to be recycled by an ink recycling unit 19. The ink recycling unit reconditions the ink and feeds it back to reservoir 28. Such ink recycling units are well known in the art. The ink pressure suitable for optimal operation will depend on a number of factors, including geometry and thermal properties of the nozzles and thermal properties of the ink. A constant ink pressure can be achieved by applying pressure to ink reservoir 28 under the control of ink pressure regulator 26.

[0022] The ink is distributed to the back surface of printhead 16 by an ink channel device 30. The ink preferably flows through slots and/or holes etched through a silicon substrate of printhead 16 to its front surface, where a plurality of nozzles and heaters are situated. With printhead 16 fabricated from silicon, it is possible to integrate drop deflection control circuits 13 and heater control circuits 14 with the printhead.

[0023] Figure 2(a) is a cross-sectional view of one nozzle tip of an array of such tips that form continuous ink jet printhead 16 of Figure 1 according to a preferred embodiment of the present invention. An ink delivery channel 40, along with a plurality of nozzle bores 46 are etched in a substrate 42, which is silicon in this example. Delivery channel 40 and nozzle bores 46 may be formed by anisotropic wet etching of silicon, using a p^+ etch stop layer to form the nozzle bores. Electrically conductive ink 70 in delivery channel 40 is pressurized above atmospheric pressure, and forms a stream 60. At a distance above nozzle bore 46, stream 60 breaks into a plurality of drops 66 due to heat supplied by a heater 50.

[0024] An electrode 83 is positioned in or near bore 46 in order to make an electrical contact with electrically conductive ink 70. Alternatively, electrical contact to ink 70 may be made by conductive surfaces, such as metallic surfaces, which could be used to form the walls of delivery channel 40.

[0025] A set of deflection electrodes 65 are on the surface of a deflection electrode spacing plate 62. Preferably, the thickness of deflection electrode spacing plate 62 is less than or about the distance from the nozzle to the point in the stream at which the stream breaks into drops due to heat supplied by the heater. Thereby, stream 60 is deflected by an electric field resulting from a potential difference applied between a set of deflection electrodes 65 and ink 70 by drop deflection control circuits 13 of Figure 1. This technology is distinct from that of prior systems of electrostatic continuous stream deflection printers, which rely upon deflection of charged drops previously separated from their respective streams.

[0026] Deflection electrode spacing plate 62 may be formed from silicon or other suitable materials. Holes may be formed in the deflection electrode spacing plate by etching techniques similar to that used to form nozzle bores 46. Metal electrodes 65 may be patterned on the surface by techniques well known in the art. The deflection electrode spacing plate may be processed separately from printhead 16 and subsequently aligned and bonded with the printhead. Such alignment and bonding techniques are well known in the art. It is recognized that other materials and geometries may be used to produce electric fields capable of deflecting continuous ink jet streams 60.

[0027] With stream 60 being deflected, drops 66 may be blocked from reaching recording medium 18 by a cut-off device such as an ink gutter 17. It is recognized that deflection may be achieved by one or more electrodes placed on the surface of deflection electrode spacing plate 62. With no potential difference applied to deflection electrodes 65 and ink 70, ink drops 67 will not be blocked by ink gutter 17. The potential difference applied to deflection electrodes 65 and ink 70 may vary with time allowing individual drops to be blocked by ink gutter 17, as shown in Figure 2(a). In an alternate embodiment of the present invention, ink gutter 17 may be placed to block undeflected ink drops 67 so that deflected ink drops 66 will be allowed to reach recording medium 18.

[0028] In the illustrated embodiment of the present invention, the nozzle is of cylindrical form, with heater 50 forming an annulus. The heater is made of polysilicon doped at a level of about thirty ohms/square, although other resistive heater material could be used. The width of heater 50 in this example is between about 0.6 μm and 0.8 μm. Heater 50 is separated from substrate 42 by thermal and electrical insulating layers 56 to minimize heat loss to the substrate. The layers in contact with the ink can be passivated with a thin film layer 64 for protection. The printhead surface can be coated with a hydrophobizing layer 68 to prevent accidental spread of the ink across the front of the printhead.

[0029] Figure 2(b) is a top view of a single nozzle of continuous ink jet printhead 16 shown in Figure 2(a). Heater annulus 50 surrounds nozzle bore 46. A set of power and ground connections 59 from the drive circuitry to heater annulus 50 are shown and are fabricated to lie at about the heater plane below the opening in deflection electrode spacing plate 62.

[0030] Heater control circuit 14 supplies electrical power to the heater sections in order to cause stream 60 to break up into drops 66 as shown in Figure 2(a). The time duration for optimal operation will depend on the geometry and thermal properties of the nozzles, the pressure applied to the ink, and the thermal properties of the ink. It is recognized that minor experimentation may be necessary to achieve the optimal conditions for a given geometry and ink.

Experimental Results

[0031] A printhead with 16 μm diameter nozzles was fabricated as described above except for deflection electrode spacing plate 62. In place of the deflection electrode spacing plate, a metal probe was placed in the vicinity of ink stream 60. An electric field was produced by applying a potential difference between the probe and ink 70. An ink reservoir and pressure control means was used to regulate the pressure of ink stream 60. A fast strobe and a CCD camera were used to freeze the image of the drops in motion. A heater power supply was used to provide an electrical current pulse to heater 50. The ink reservoir was filled with DI water and a pressure of about 10 lbs./in^2 (68.9 kPa) was applied, forming ink stream 60. A pulse train of 400 ns pulses at a repetition rate of 98 KHz and a power of 96 mW was applied to heater 50, causing the stream to break up into a series of regularly spaced drops as can be seen in Figure 3(a). When a potential difference of 400 volts was applied between the probe and stream 60, the drops were deflected at an angle of approximately 20 degrees, as shown in Figure 3(b). This large deflection angle is much greater than that needed in a printing apparatus. Smaller deflection angles, and hence lower voltages, could be used.

[0032] Although an array of streams is not required in the practice of this invention, a device comprising an array of streams may be desirable to increase printing rates. In this case, deflection and modulation of individual streams may be accomplished as described for a single stream in a simple and physically compact manner, as provided by conventional integrated circuit technology, for example CMOS technology.

[0033] The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

Claims

1. Apparatus for controlling ink in a continuous ink jet printer in which a continuous stream of ink is emitted from a nozzle; said apparatus comprising:

    an ink stream generator which establishes a continuous flow of ink in a stream, said stream breaking up into a plurality of droplets at a position spaced from the ink stream generator; and
    a stream deflector adjacent to the stream between the ink stream generator and the position whereat the stream breaks up into droplets to control the direction of the stream between a print direction and a non-print direction.

2. Apparatus for controlling ink in a continuous ink jet printer in which a continuous stream of ink is emitted from a nozzle; said apparatus comprising:

    an ink stream generator which establishes a continuous flow of ink in a stream;
    a droplet generator which causes the stream to break up into a plurality of droplets at a spaced position from the ink stream generator; and
    a stream deflector adjacent to the stream between the ink stream generator and the position whereat the stream breaks up into droplets to control the direction of the stream between a print direction and a non-print direction.

3. Apparatus as set forth in Claims 1 and 2, further comprising an ink gutter in the path of ink droplets traveling in said non-print direction.

4. Apparatus as set forth in Claims 1 and 2, further comprising an electrode associated with the ink delivery channel to make an electrical contact with the ink stream; and wherein the stream deflector comprises:

    at least one deflection electrode; and
    a deflection control circuit adapted to selectively apply to said deflection electrode an electrical potential of a potential to deflect droplets from one of said print and non-print directions to the other of said print and non-print directions.

5. Apparatus as set forth in Claims 1 and 2, wherein the droplet generator is a heater.

6. Apparatus as set forth in Claims 1 and 2, wherein the ink stream generator comprises:

    an ink delivery channel;
    a source of ink communicating with the ink delivery channel, wherein the ink is pressurized above atmospheric pressure; and
    a nozzle bore which opens into the ink delivery channel.

7. A process for controlling ink in a continuous ink jet printer in which a continuous stream of ink is emitted from a nozzle; said process comprising:

    establishing a continuous flow of ink in a stream which breaks up into a plurality of droplets at a position spaced from the nozzle; and
    deflecting the ink stream before the position whereat the stream breaks up into droplets to thereby control the direction of the stream between a print direction and a non-print direction.

8. A process for controlling ink in a continuous ink jet printer in which a continuous stream of ink is emitted from a nozzle; said process comprising:

    establishing a continuous flow of ink in a stream;
    causing the stream to break up into a plurality of droplets at a position spaced from the nozzle; and
    deflecting the ink stream before the position whereat the stream breaks up into droplets to thereby control the direction of the stream between a print direction and a non-print direction.

9. The process as set forth in Claims 7 and 8, wherein the step of establishing a continuous flow of ink in a stream comprises:

    providing an ink delivery channel;
    providing a source of ink communicating with the ink delivery channel;
    pressurizing the ink in the delivery channel above atmospheric pressure; and
    providing a nozzle bore which opens into the ink delivery channel.

10. The process as set forth in Claims 7 and 8, wherein the step of establishing a continuous flow of ink in a

stream comprises:

providing an ink delivery channel;
providing a source of ink communicating with the ink delivery channel;
pressurizing the ink in the delivery channel above atmospheric pressure; and
providing a nozzle bore which opens into the ink delivery channel.

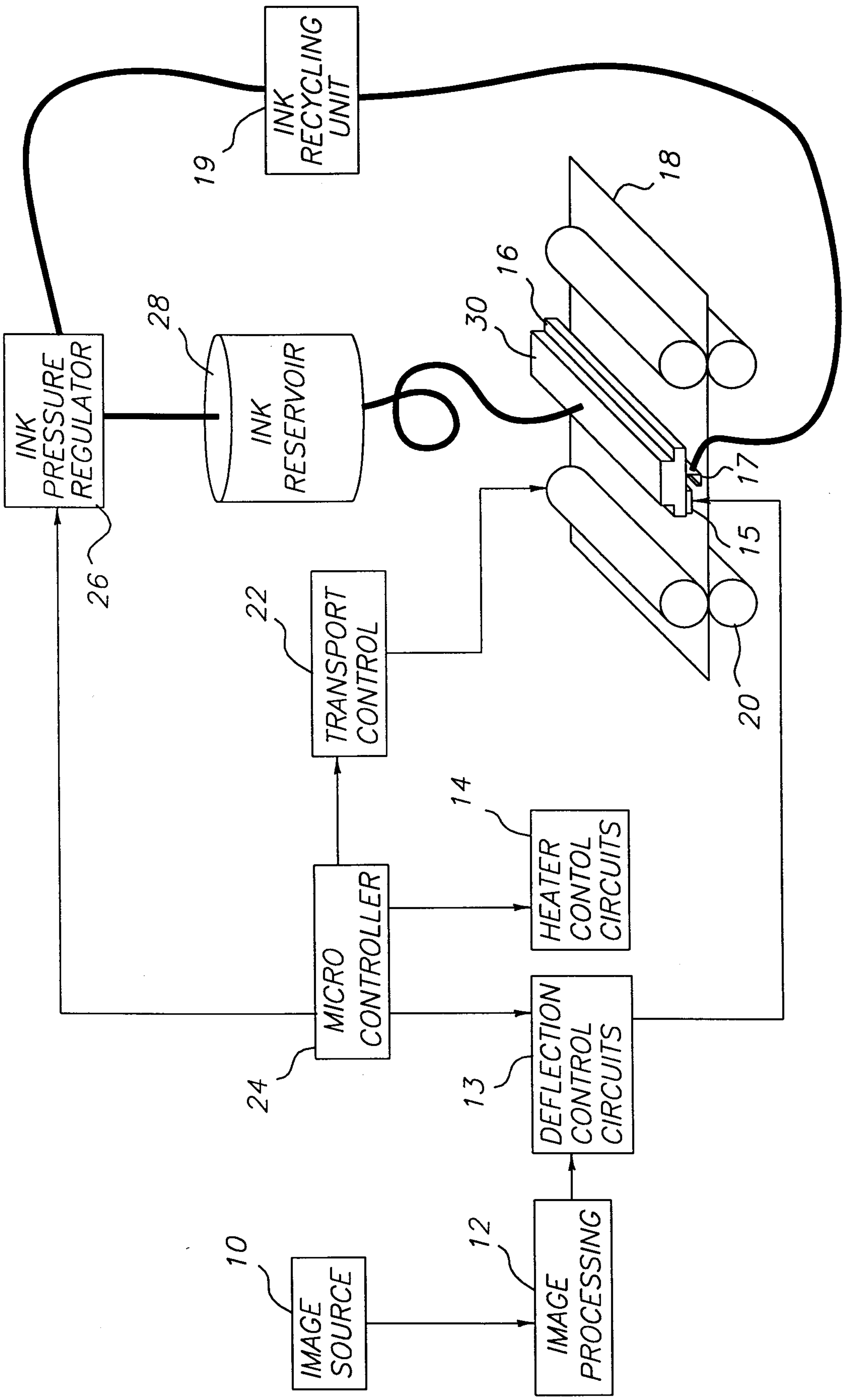
INK RECYCLING UNIT
19
18
16
30
28
INK PRESSURE REGULATOR
INK RESERVOIR
17
15
26
22
TRANSPORT CONTROL
20
14
HEATER CONTOL CIRCUITS
MICRO CONTROLLER
24
13
DEFLECTION CONTROL CIRCUITS
10
12
IMAGE SOURCE
IMAGE PROCESSING

FIG. 1

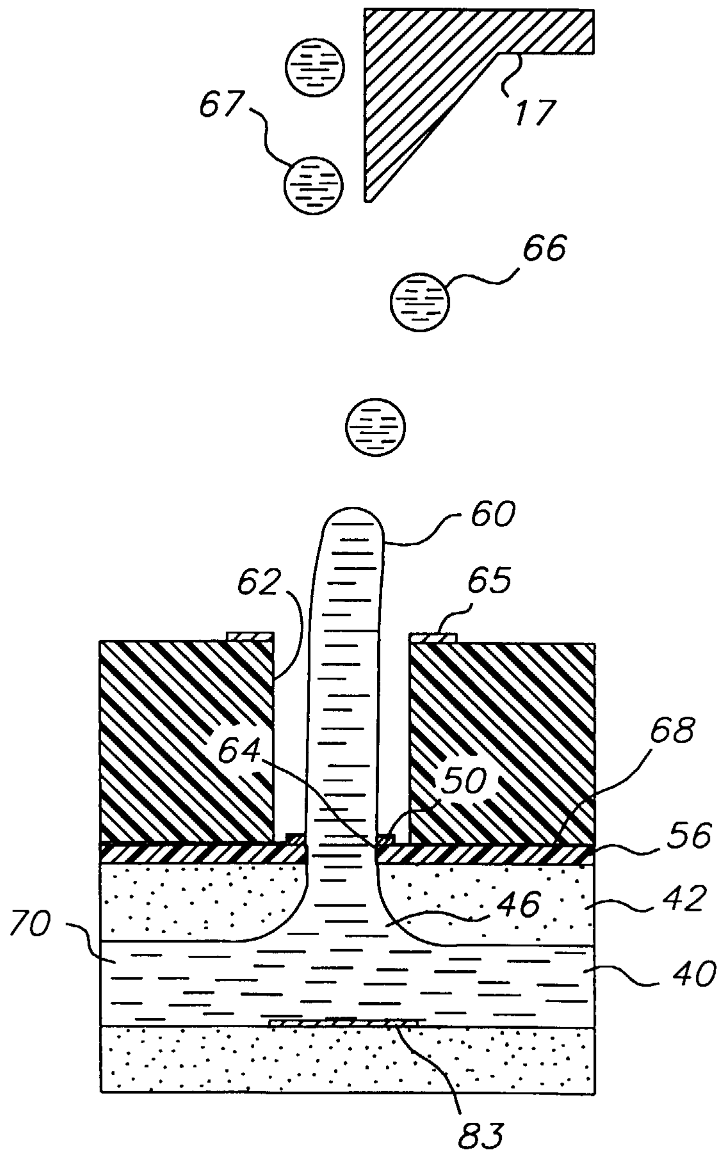

FIG. 2A

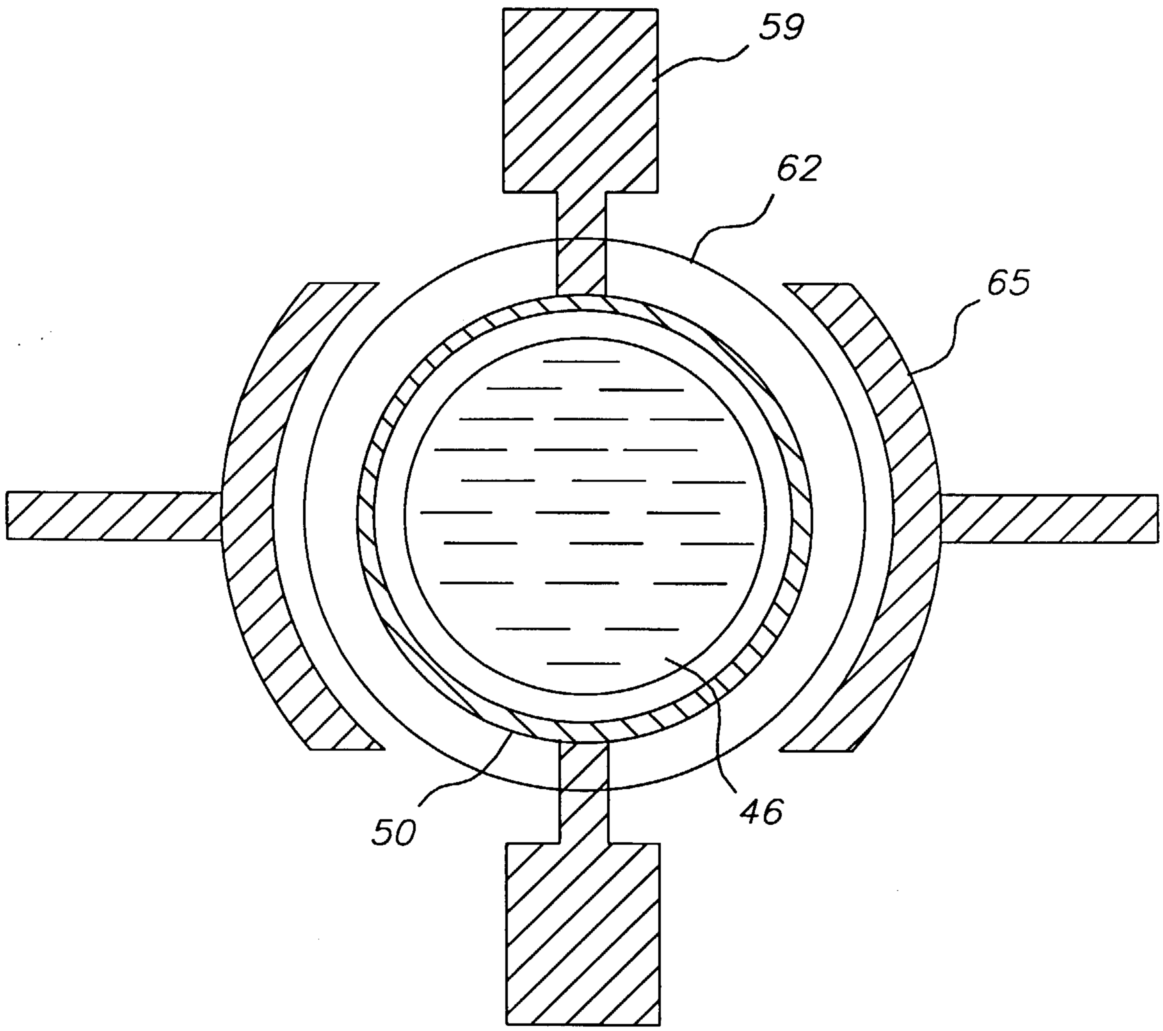

FIG. 2b

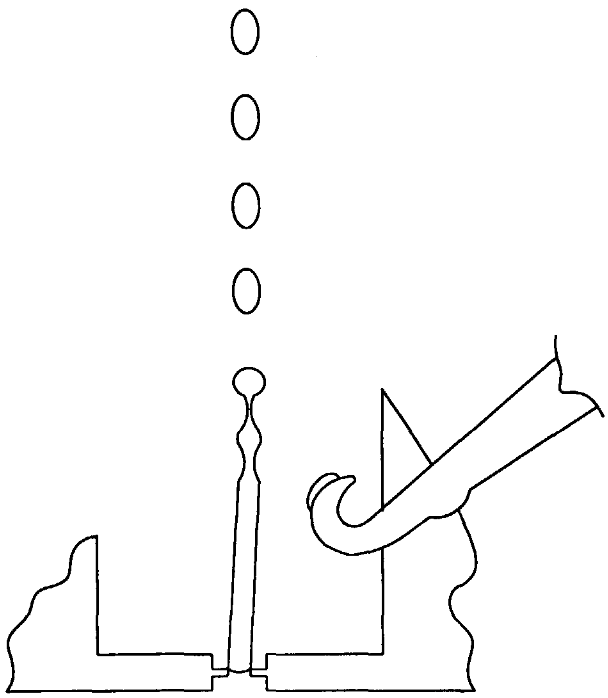

FIG. 3a

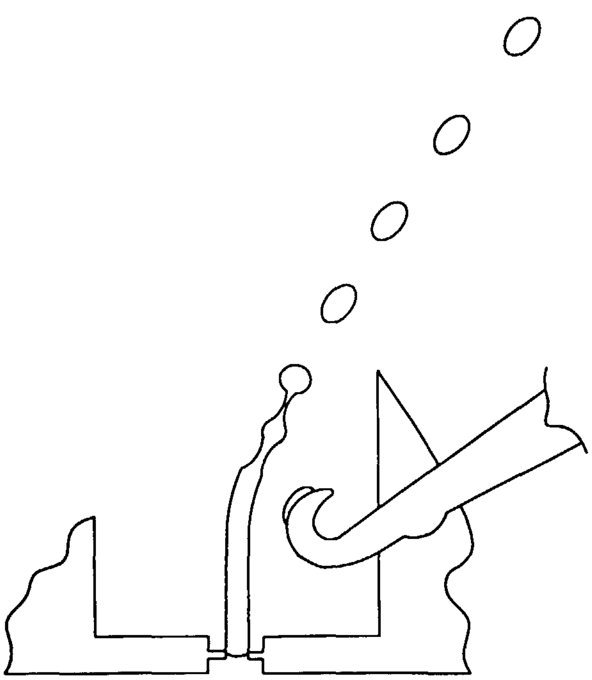

FIG. 3b