

(19)



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(11)

EP 0 873 871 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

28.10.1998 Bulletin 1998/44(51) Int Cl.⁶: **B41J 2/14, B41J 2/05**(21) Application number: **98302015.7**(22) Date of filing: **18.03.1998**

(84) Designated Contracting States:

AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT

Designated Extension States:

AL LT LV MK RO SI(30) Priority: **27.03.1997 US 826324**(71) Applicant: **Xerox Corporation****Rochester, New York 14644 (US)**

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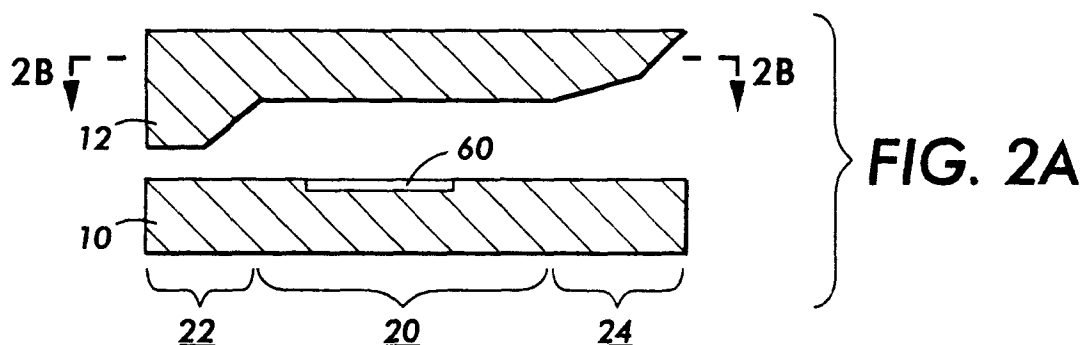
(74) Representative:

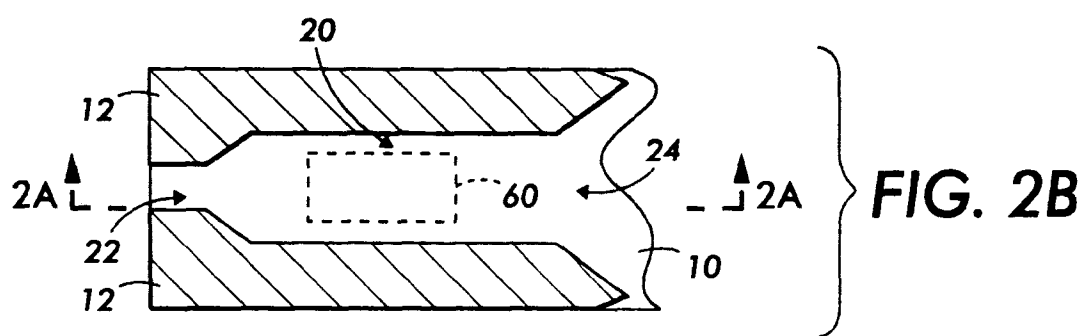
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(54) Thermal ink jet printhead suitable for viscous inks

(57) A thermal ink-jet printhead includes ejectors which define channels for the passage of liquid ink therethrough. A heating element (60) for nucleating liquid ink is disposed in a heating portion (20) of each channel. A nozzle portion (22) of the channel is smaller in

cross-sectional area than the heating portion (20), and a manifold portion (24), through which new liquid ink enters the heating portion (20), is larger in cross-sectional area than the heating portion (20). The design is advantageous for ejecting inks of viscosity greater than 2 centipoise.

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Description

The present invention relates to a printhead for a thermal ink-jet printer, in which the fluid flow channel of each ejector is specially shaped for optimal performance, particularly in ejecting liquid inks of greater than 2 centipoise viscosity.

In thermal ink-jet printing, droplets of ink are selectively ejected from a plurality of drop ejectors in a printhead. The ejectors are operated in accordance with digital instructions to create a desired image on a print sheet moving relative to the printhead. The ejectors typically comprise capillary channels, or other ink passageways, which are connected to one or more common ink supply manifolds. Ink is retained within each channel until, in response to an appropriate digital signal, the ink in the channel is rapidly heated by a heating element disposed on a surface within the channel. This rapid vaporization of the ink adjacent the channel creates a bubble which causes a quantity of liquid ink to be ejected through an opening associated with the channel to the print sheet. The process of rapid vaporization creating a bubble is generally known as "nucleation."

In most designs of a thermal ink jet ejector, the volume of the cavity around the heating element is relatively large, with narrower portions to the front and the rear of the heating element. The narrow portion in the nozzle region limits the volume of the drop which is pushed out of the ejector, prevents ingestion of air into the cavity, and provides a capillary force for rapid refill after a droplet of ink is ejected. The narrow portion on the manifold (ink-supply) side contains the bubble formed over the heating element, limits the backward flow of ink during and after nucleation, and dampens the ink refill to prevent ink from bulging out the nozzle once the cavity is refilled.

US-A-4,368,477 discloses an ink-jet printhead in which individual ejectors are each provided with a diagonally-extending ink duct. The downstream end of each duct is formed with a wedge-shaped tapered portion, each having a leading edge wall carrying a discharge orifice for ink droplets.

US-A-4,550,326 discloses a nozzle plate for a "roof-shooter" printhead in which, as shown in Figures 8A and 8B, the orifices are tapered in front of the ink meniscus.

US-A-4,675,693 discloses an ink-jet printhead in which the minimum cross-sectional area of a "discharge port" is optimized with respect to the volume of the droplets intended to be discharged.

US-A-5,041,844 discloses a thermal ink-jet printhead having a channel geometry that controls the location of the bubble collapse on the heating elements. In one embodiment, the heating elements are located in a pit, and the channel portion upstream from the heating element has a length and cross-sectional flow area that is adjusted relative to the channel portion downstream from the heating element, so that the upstream and downstream portions of the channel have substantially

equal ink flow impedances.

US-A-5,148,192 and US-A-5,371,528 discloses a thermal ink-jet printhead in which each ejector has a channel which includes one portion, between the heating element and the orifice through which ink is ejected onto the sheet, which tapers outwardly toward the orifice, and a second portion, immediately adjacent the orifice, which tapers inwardly toward the orifice.

US-A-5,361,087 discloses a thermal ink-jet printhead in which, for each ejector, the orifice through which ink is ejected onto the sheet is of trapezoidal cross-section, and tapers in cross-section toward the opening thereof.

US-A-5,552,813 shows a design of a ink jet head which is intended specifically to minimize effects of viscous drag on droplet ejection. A plurality of pressure chambers are arranged in a circle around an array of nozzles. The nozzles are arranged in a zig-zag form, and firing control of the ejectors is adapted accordingly.

Japanese laid-open publication JP-A-06320731 discloses a baseplate for "liquid passages" in which channels etched into the surface of the baseplate include a special section of the channel which is greater in cross section than the remainder of the channel, such as near a nozzle.

US patent 4,994,826 discloses one proposed design of a "side-shooter" thermal ink-jet printhead. A simplified rendering of the basic printhead design shown in this patent is hereshown as Figure 1. According to any typical design of a side-shooter ink-jet printhead, the individual ejectors in the printhead are formed essentially along the abutment between a "heater chip," here indicated in Figure 1 as 10, and a "channel plate," indicated here in Figure 1 as 12. According to the design in the '826 patent, there is disposed between the abutting surfaces of heater chip 10 and channel plate 12 a "thick film insulative layer" indicated here as 50 (shown in two parts in the sectional elevational view of Figure 1). For each ejector in the prior art printhead of Figure 1, there is disposed in the channel plate 12 two cavities, a manifold 52 and a channel 54. Within the channel plate 12 itself, the manifold 52 and the channel 54 are not directly connected to each other; rather, as shown in Figure 1, the manifold 52 communicates with channel 54 via a recess, here indicated as 56, which is disposed in the thick-film insulative layer 50. Within the channel 54 of each ejector in the printhead, there is disposed a heating element 60 which is operatively attached through circuitry, the general structure of which is indicated as 58, to a source of voltage. As with any thermal ink-jet printhead, application of voltage to heating element 60 causes the desired nucleation of adjacent liquid ink, in this case the liquid ink maintained at any time within channel 54 of a particular ejector.

It will be noted that the particular structure of the prior art printhead in Figure 1 shows the heating element 60 disposed within a "pit" within channel 54, and that the actual nozzle 62, out of which liquid ink is ejected is with-

in the same plane as the thick film insulative layer 58. The overall purpose of this structure, as described in the referenced patent, is to minimize the fluidic effects of back-pressure as the ink nucleates against ink in the manifold 52, and also prevent ingestion of outside air through nozzle 62 immediately following each ejection. The printhead structure is dependent on the thick-film insulative layer 50, which is typically made of a material such as polyimide, sandwiched between the main planes of the heater chip 10 and the channel plate 12.

According to one aspect of the present invention, there is provided an ink-jet printing apparatus having at least one ejector, the ejector comprising a structure defining a channel adapted for flow of liquid ink there-through and a heating element disposed within the channel. The channel includes a heating portion directly adjacent the heating element, a nozzle portion adjacent a first end of the heating portion along the channel, and a manifold portion adjacent a second end of the heating portion along the channel. The nozzle portion has a cross-sectional area smaller than a cross-sectional area of the heating portion, and the manifold portion has a cross-sectional area greater than the cross-sectional area of the heating portion.

According to another aspect of the present invention, there is provided an ink jet printing apparatus, comprising a heater chip defining a planar main surface, the heater chip including a selectably actuable heating element on the main surface, and a channel plate directly abutting the main surface of the heater chip. A channel is defined in the channel plate, extending along an axis. The channel includes a heating portion directly adjacent the heating element, a nozzle portion adjacent a first end of the heating portion along the axis, and a manifold portion adjacent a second end of the heating portion along the axis. The nozzle portion has a cross-sectional area smaller than a cross-sectional area of the heating portion, and the manifold portion has a cross-sectional area greater than the cross-sectional area of the heating portion. The channel plate is made of a single piece of material.

According to yet another aspect of the present invention, there is provided a method of operating an ejector in an ink-jet printhead. An ejector includes a structure defining a channel, and a heating element disposed within the channel. The channel includes a heating portion directly adjacent the heating element, a nozzle portion adjacent a first end of the heating portion along the channel, the nozzle portion having a cross-sectional area smaller than a cross-sectional area of the heating portion, and a manifold portion adjacent a second end of the heating portion along the channel, the manifold portion having a cross-sectional area greater than the cross-sectional area of the heating portion. Liquid ink of a viscosity greater than 2 centipoise at operating temperature is supplied into the channel. The heating element is actuated to nucleate liquid ink in the channel and cause a quantity of liquid ink to be ejected from the

nozzle portion, this actuating step occurring more than 20,000 times per second.

The present invention describes an ejector design in which the manifold side of the ejector cavity is considerably wider than the portion around the heating element, providing little physical restriction on the ink on the manifold side. The function of the usual restriction on the manifold side is provided by a combination of a narrowed nozzle portion and the viscosity of the ink itself. This "open" geometry provides a rapid refill after nucleation, which is aided by the collapse of the vapor bubble.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a simplified sectional elevational view of an ink-jet ejector known in the prior art;

Figure 2A is a sectional elevational view, and Figure 2B is a sectional plan view through line 2B in Figure 2A, of a cavity forming a single ejector in an ink-jet printhead according to one embodiment of the present invention;

Figure 3 is a perspective view showing the cavity shape of a single ejector such as shown in Figures 2A and 2B;

Figure 4A is a sectional elevational view, and Figure 4B is a sectional plan view through line 4B in Figure 4A, of a cavity forming a single ejector in an ink-jet printhead according to an alternative embodiment of the present invention; and

Figure 5 is a plan view of a channel for ejecting ink according to yet another embodiment of the present invention.

Figure 2A is a sectional elevational view, and Figure 2B is a sectional plan view, of a cavity forming a single ejector in an ink-jet printhead according to one embodiment of the present invention. As can be seen in the Figures, the ejector includes a channel which is formed at the abutment of a main, planar surface of a heater chip 10 and a channel plate 12. According to this embodiment of the present invention, the main surface of heater chip 10 is substantially planar, and disposed within the planar main surface of heater chip 10 is a heating element 60 a general design of which will be known in the art, which is in turn connected to a source of selectably-actuable voltage (not shown). When the channel plate 12 is abutted against the heater chip 10, the heating element 60 in each ejector is disposed immediately adjacent what shall here be called a "heating portion" of a channel formed in channel plate 12, which is here indicated as 20.

Immediately adjacent the heating portion of the channel in channel plate 12 is a smaller channel, which is here called a nozzle portion 22, and, at the opposite end of heating portion 60 is a larger cavity made in channel plate 12, which is here called a manifold portion 24.

It will be seen, from the Figures, that manifold portion 24, heating portion 20, and nozzle portion 22 together form a channel with the cross-sectional area of the large cavity formed in channel plate 12 becoming progressively smaller in cross-sectional area from the manifold portion 24 through heating portion 20 and finally to nozzle portion 22.

Figure 3 is a perspective view of a single ejector such as shown in Figures 2A and 2B. Outlined in dotted lines in Figure 3 is the shape of a single cavity which, according to a preferred embodiment of the present invention, is formed in channel plate 12 for each ejector. According to one embodiment of the present invention, the nozzle portion 22, heating portion 20, and manifold portion 24 are formed as cavities in channel plate 12, which is a single, monolithic piece of silicon for a larger number of ejectors in a printhead. As shown in Figure 3, the nozzle portion 22 and the heating portion 20 are generally triangular in shape when viewed in cross-section perpendicular to the axis of fluid flow, with one side of the triangle being formed by the main planar surface of heater chip 10, and the other two sides of the triangle being formed by the $\langle 111 \rangle$ plane of the crystal structure of the silicon forming channel plate 12. Such a structure as shown in Figure 3 can be obtained through orientation-dependent etching of silicon. At the junction 21, for example, between nozzle portion 22 and heating portion 20 the exposed plane of the silicon forming channel plate 12 is typically substantially the $\langle 210 \rangle$ plane of the silicon. Similarly, the main surfaces of manifold portion 24 can be formed from the $\langle 111 \rangle$ planes of channel plate 12 as well, with the junction 23 therebetween formed at least partially by $\langle 210 \rangle$ planes as well. It is also conceivable to provide a channel plate 12 of a desired configuration of a plastic material; it is generally desirable, whatever material is used for the channel plate, to make the effective portions thereof defining the various portions of the ejector of a single piece of material.

The junctions 21 and 23 between the heating portion 20 and the nozzle portion 22 and manifold portion 24 preferably create distinct "steps," or transition regions, in the decreasing cross-section of the channel along the axis from the ink supply to the nozzle portion 22; these steps should be distinguished from designs in which the cross-section of the channel from a manifold portion to a nozzle decreases continuously. Nonetheless, at the steps 21 and 23 between the heating portion 20 and the nozzle portion 22 and manifold portion 24, the channel may be tapered, as shown in Figure 3, so as to avoid undesirable sources of flow impedance which may be caused by abrupt changes in cross-sectional area.

According to one preferred embodiment of the present invention, the nozzle portion 22 should be significantly smaller in all dimensions than the heating portion 20. In one embodiment for a 600 dpi printhead, if the nozzle portion 22 is 20 micrometers in length along the axis of fluid flow, a preferred length of the heating

portion 20 along the axis is from 60 to 200 micrometers, including the length taken up by the step 21 between the nozzle portion 22 and heating portion 20. Also, a preferred range of lengths from the front opening of nozzle portion 22 (i.e., the front face of the printhead) and the front edge of the heating element 60 is 40-70 micrometers. Corresponding preferred lengths along the axis of the heating element 60 range from 25 to 100 micrometers. Similarly, a preferred cross-sectional width for the nozzle portion 22 is between 10 and 20 micrometers, while a corresponding preferred range of cross-sectional widths of the heating portion 20 is 20 to 30 micrometers; given particular cross-sectional shapes of the heating portion 20 and nozzle portion 22 and given that each portion may taper somewhat along the length of the channel, the cross-sectional area of the bulk of the heating portion 20 should be generally at least twice that of the bulk of the nozzle portion 20.

In general, these ranges of relative dimensions within the cavity forming the ejector have been found to be useful for ejecting liquid inks of relatively high viscosity, in particular, viscosities in excess of 2 centipoise for ink immediately adjacent the heating element 60 at normal operating temperatures just before ejection. The above-described relative dimensions are useful in ejecting ink of approximately 3.5 centipoise at operating temperature, though reasonably satisfactory results can be obtained with viscosities up to 12 centipoise. Also, it will be understood that the above-described dimensions for a 600 dpi printhead could be scaled to obtain printheads for other resolutions, such as 300 dpi.

A key practical advantage of the printhead design of the present invention is that the relative sizes of the manifold portion 24, heating portion 20, and nozzle portion 22 reduce many of the performance difficulties which arise when liquid ink is attempted to be ejected from the ejector at high frequencies. A key functional limitation to any thermal ink-jet printhead design is the speed at which an ejector can re-fill with liquid ink from an ink supply manifold immediately after the ejection of a droplet through the nozzle. With the printhead design of the present invention, the combination of a relatively narrow nozzle portion 22 and a relatively "open" manifold portion 24 facilitates a high speed of re-fill of liquid ink into heating portion 20 immediately after a nucleated vapor bubble collapses within the heating portion 20. Thus, an ejector according to the present invention is capable of accurately producing discrete ink droplets of small drop volumes and at high operating frequencies. With cavity dimensions in the above-described ranges, and using liquid ink of a viscosity of more than 2 centipoise or preferably 3.5 centipoise, an ejector can consistently eject droplets at a rate in excess of 20,000 ejections per second without the failures caused by, for example, ingestion of air into the nozzle portion 22 or insufficient liquid ink being supplied through manifold portion 24.

Figure 4A is a sectional elevational view, and Figure

4B is a sectional plan view of a cavity forming a single ejector in an ink-jet printhead according to another embodiment of the present invention based on a "top shooter" type ink jet geometry. As can be seen in the Figures, the ejector includes a nozzle portion 22 which is directly above the heating element 60, a heating portion 20 around the heater, and a manifold portion 24 which is connected to an ink supply (not shown). According to this embodiment of the present invention, the heating portion 20 is not restricted but is of constant cross section until the transition region 23 which expands to meet the manifold portion 24, as shown in Figure 4B. As with the design shown in Figures 2A and 2B and 3, this design provides a large opening to the manifold region which serves to provide the maximum possible refill capability. The dampening of the refill is provided by the viscosity of the ink rather than by a restriction in the back channel.

Figure 5 shows an alternate embodiment of a general shape of an ejector according to the present invention, in which there is provided, between heating portion 20 and manifold portion 24, a constriction indicated as 30. The cross-section of the constriction is smaller than the overall cross-section of the heating portion 20. Such a constriction may have a desirable effect of reducing vibrational "cross-talk" among adjacent ejectors in a printhead array, which is ordinarily caused by the back-pressure of an expanding vapor bubble from one ejector increasing pressure within an ink manifold shared by multiple ejectors. The constriction 30 should create a cross-sectional area in the channel which is less than 20%, and preferably less than 10%, smaller than the cross-sectional area of an immediately adjacent portion of the heating portion 20.

While the invention has been described with reference to the structure disclosed, it is not confined to the details set forth, but is intended to cover such modifications or changes as may come within the scope of the following claims.

Claims

1. An ink-jet printing apparatus having at least one ejector, the ejector comprising:

a structure (12,10) defining a channel, the channel adapted for flow of liquid ink there-through; and

a heating element (60) disposed within the channel;

the channel including a heating portion (20) directly adjacent the heating element (60), a nozzle portion (22) adjacent a first end of the heating portion (20) along the channel, the nozzle portion having a cross-sectional area smaller than a cross-sectional area of the heating portion (20), and a manifold portion (24) adjacent

a second end of the heating portion along the channel, the manifold portion (24) having a cross-sectional area greater than the cross-sectional area of the heating portion (20).

2. The apparatus of claim 1, wherein the heating portion (20) is longer along the channel than the nozzle portion (22).
3. The apparatus of claim 2, wherein the heating portion (20) is more than twice as long along the channel as the nozzle portion (22).
4. The apparatus of claim 3, wherein the heating portion (20) is between three and ten times as long along the channel as the nozzle portion (22).
5. The apparatus of any preceding claim, wherein the cross-sectional area of the heating portion (20) is at least twice the cross-sectional area of the nozzle portion (22).
6. The apparatus of any preceding claim, wherein the channel defines a step (21) between the heating portion (20) and the nozzle portion (22).
7. The apparatus of any preceding claim, wherein the channel defines a step (23) between the manifold portion (24) and the heating portion (20).
8. The apparatus of any preceding claim, wherein the channel includes a constriction (30) between the manifold portion (24) and the heating portion (20), the constriction (30) defining a cross-sectional area smaller than a cross-sectional area of the heating portion (20).
9. The apparatus of claim 8, wherein the constriction (30) defines a cross-sectional area less than 20% smaller than a cross-sectional area of a directly adjacent portion of the heating portion (20).
10. The apparatus of claim 9, wherein the constriction (30) defines a cross-sectional area less than 10% smaller than the cross-sectional area of the directly adjacent portion of the heating portion (20).
11. An ink jet printing apparatus according to any preceding claim, comprising:
 - a heater chip (10) defining a planar main surface, the heater chip (10) including a selectably actuatable heating element (60) on the main surface;
 - a channel plate (12) directly abutting the main surface of the heater chip (10); and
 - a channel defined in the channel plate adjacent the heating element (60), the channel extend-

ing along an axis, the channel including a heating portion (20) directly adjacent the heating element (60), a nozzle portion (22) adjacent a first end of the heating portion (60) along the axis, the nozzle portion having a cross-sectional area smaller than a cross-sectional area of the heating portion; and the channel plate (12) being defined by a single piece of material.

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12. The apparatus of claim 11, wherein the channel plate (12) is defined by a single piece of silicon.

13. The apparatus of claim 11, the channel being defined by a single piece of plastic.

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14. The apparatus of claims 11, 12 or 13, wherein the heating portion (20) and nozzle portion (22) each define at least two planes in the channel plate, each of said two planes being a <111> plane in the single piece of material.

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15. A method of operating an ejector in an ink-jet print-head, comprising the steps of:

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providing in the ejector a structure defining a channel, and a heating element (60) disposed within the channel, the channel including a heating portion (20) directly adjacent the heating element (60), a nozzle portion (22) adjacent a first end of the heating portion (20) along the channel, the nozzle portion (22) having a cross-sectional area smaller than a cross-sectional area of the heating portion (20), and a manifold portion (24) adjacent a second end of the heating portion (22) along the channel, the manifold portion (24) having a cross-sectional area greater than the cross-sectional area of the heating portion (20); supplying into the channel liquid ink of a viscosity greater than 2 centipoise at operating temperature; and actuating the heating element (60) to nucleate liquid ink in the channel and cause a quantity of liquid ink to be ejected from the nozzle portion (22), said actuating step occurring more than 20,000 times per second.

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16. The method of claim 15, wherein the supplying step includes supplying into the channel liquid ink of a viscosity of approximately 3.5 centipoise at operating temperature.

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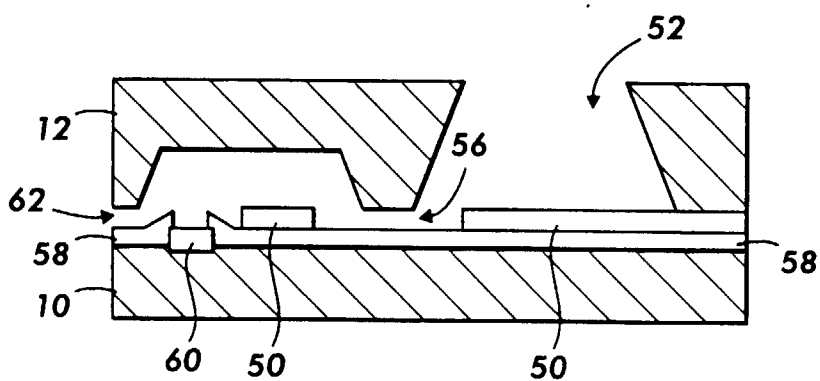


FIG. 1
PRIOR ART

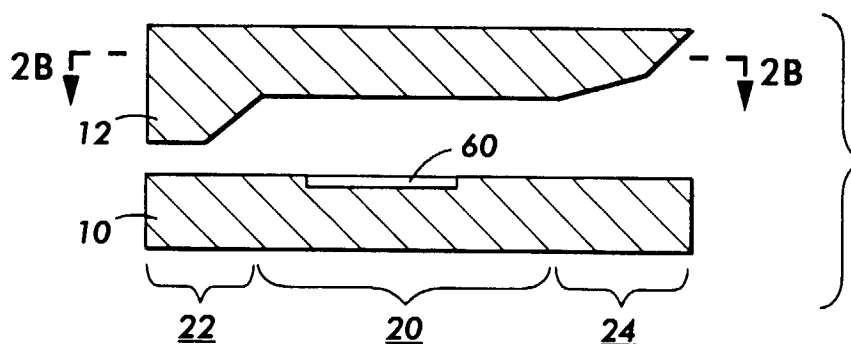


FIG. 2A

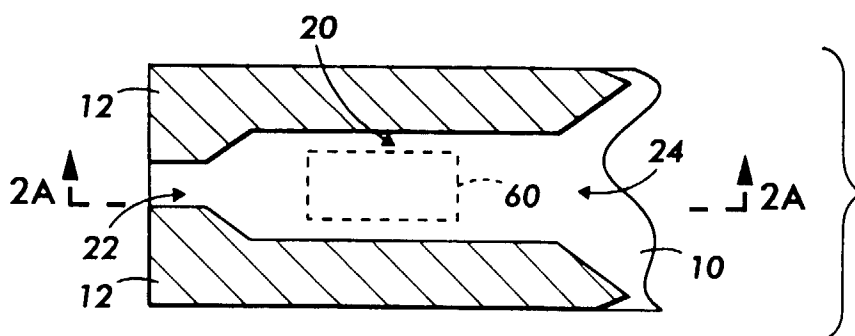


FIG. 2B

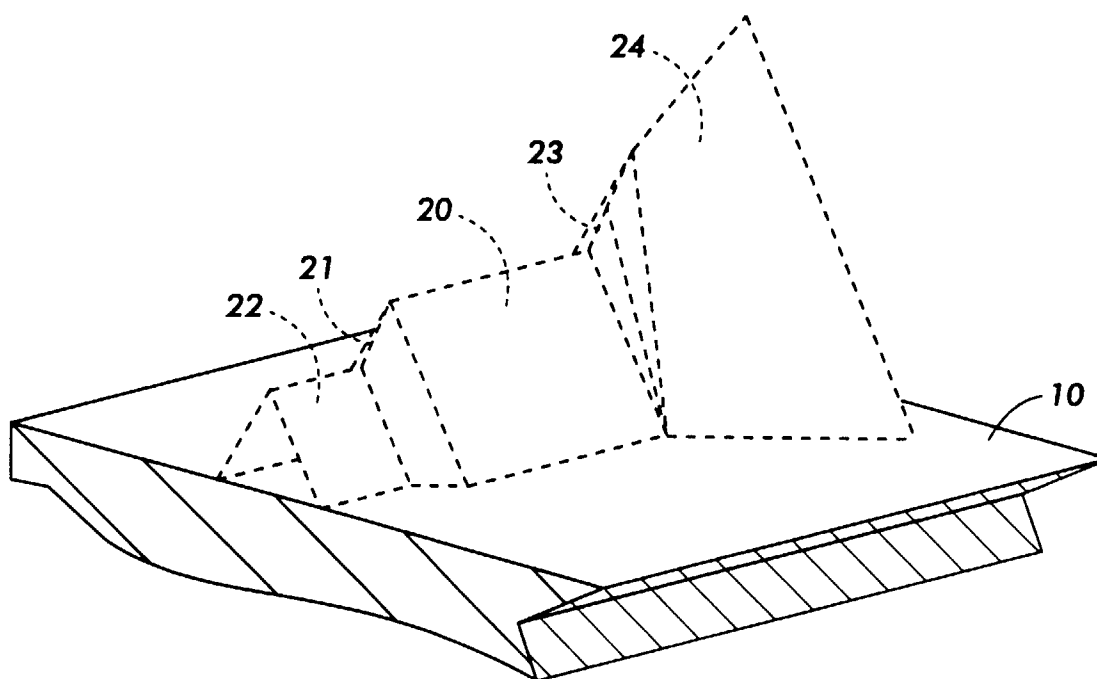


FIG. 3

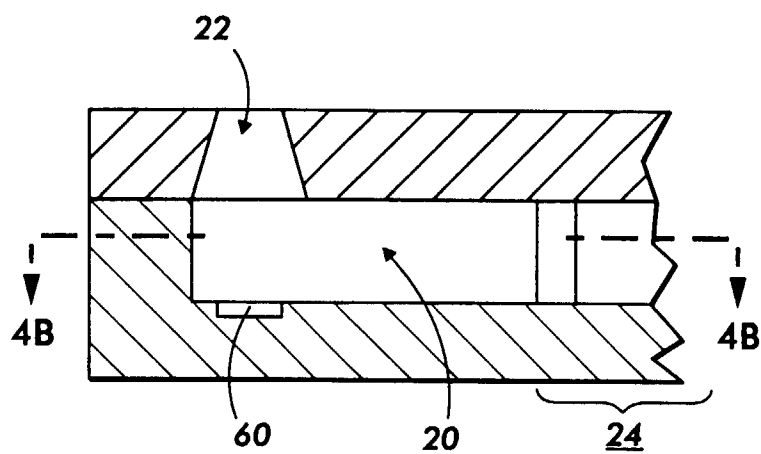


FIG. 4A

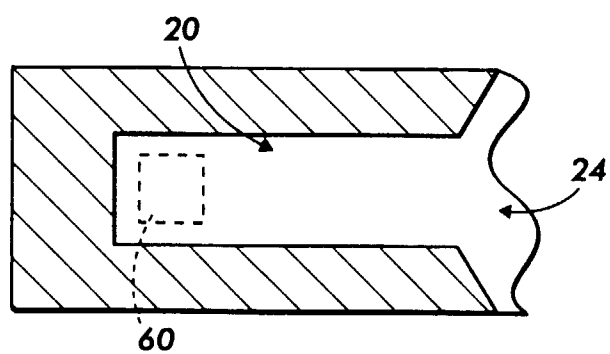


FIG. 4B

